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CONTENTS

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

This and the preceding Volume of Transactions (Vol. LXVIII) contain all the Papers descriptive of the New York Extension of the Pennsylvania Railroad. A general index covering all the papers is issued in this volume.

PLATES

ERRATA.

Transactions, Vol. LXVIII.

Page 34, line 9: For "George D. Roberts" read "George B. Roberts."

Page 159, Table 2, Summary: For the items in the Summary substitute the following:

"Cost of main items of plant in one power-house	$80 000
"Cost of minor items of plant in tunnels, surface and tunnel transportation, drills, derricks, platforms, bulkhead walls, offices, lighting, grouting and concreting plant	127 000
"Cost of two shields, including erection, demolition, additions, renewals and pumps	103 000
"Cost of plant installation, including preparation of sites	40 000
"Total for one plant	$350 000"

Page 183, Table of Drilling and Firing Data: All plus signs in this table should be multiplication signs.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1160

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. CONTRACTORS' PLANT FOR EAST RIVER TUNNELS.*

By Henry Japp, M. Am. Soc. C. E.

The minimum plant to be provided by the contractors for this undertaking was specified by the Railroad Company as follows:

"The tunnels shall be driven eastward from shafts in Manhattan and westward from the temporary shaft to be built near East Avenue in Long Island City, making a total of eight headings, in all of which work shall be prosecuted simultaneously with the utmost diligence practicable. The Contractor must provide on each side of the river an adequate plant, including boilers, air compressors, hydraulic machinery, dynamos, and all other necessary plant, with a reasonable duplication to meet unusual and unexpected emergencies.

"The air compressors shall be of sufficient capacity to deliver regularly into each heading at least 300 000 cu. ft. of free air per hour at a pressure of 50 lb. per sq. in. above the normal air pressure, and for a larger amount if found necessary during the progress of the work. The air for the compressors must be drawn from the exterior of the power-house, and the intake located so as to give pure air. The air shall be cooled, and oil and other impurities removed as completely as practicable before delivering it into the headings.

"In order to provide a reasonable margin for repairs and contingencies, a spare compressor and boiler plant shall be provided on each

* Presented at the meeting of December 15th, 1909.

side of East River and kept in good condition and repair, ready for immediate use. The capacity of the spare plant shall be 25% of that required in the preceding paragraph for regular operation.

"Provision must be made for storing in tanks at each boiler-house enough feed water for 12 hours' supply, unless connections can be made with two independent and sufficient sources of supply.

"The air shall be delivered into each heading through two supply pipes of such capacity that the velocity of air through them in regular working shall not exceed 40 ft. per sec. These pipes shall be tapped with regulating valves in each intermediate air chamber in tunnels, and sufficient air admitted to ventilate it and to maintain the pressure required. If required by the Engineer, air shall be delivered at the shield in each section or compartment thereof where men are employed, and withdrawn therefrom in special exhaust pipes, with suitable regulating valves.

"Each supply pipe shall be furnished with two tees with valves and an intermediate valve in the supply pipe at some convenient place between the compressors and the shaft to enable a by-pass to be formed.

"A foul-air vent pipe, 6 in. in diameter, shall be carried back from the shield through each lock bulkhead to the ordinary atmosphere to ventilate the heading, and shall be provided with a 10-in. pressure-regulating valve near the shield to maintain the pressure required; the valve shall be placed so as not to be readily tampered with.

"Effective means shall be used to secure proper ventilation. The amount of carbonic acid at any working face or in any chamber must never exceed one part in one thousand parts of air, and compressors must be run so as to maintain at all times a change of air through the pressure-regulating valves. Suitable devices shall be used to deaden the noise of the air introduced and exhausted as much as practicable. When blasting is resorted to, special means must be provided for the rapid removal of the fumes produced.

"Bulkheads shall be built in each tunnel at intervals not exceeding 1 000 ft., and there shall at no time be an interval of more than 1 000 ft. between a shield and the bulkhead nearest to it. They shall be of concrete or of brick set in Portland cement mortar, or other plan approved by the Engineer. Each bulkhead shall be provided with two air-locks near the bottom, at least 6 ft. in diameter and 20 ft. long, for the passage of men and materials, one near the roof as an emergency lock for the passage of men only, and a pipe-lock 12 in. in diameter and 31 ft. long, with a gate-valve at each end, for passing pipes and rails. The emergency lock shall be of ample dimensions to contain the entire force employed at any time at the heading. Stairways and galleries shall always be maintained to give convenient access thereto. All parts of bulkheads and air-locks must be of sufficient strength to sustain safely a pressure of 55 lb. per sq. in.

PLATE I.
TRANS. AM. SOC. CIV. ENGRS.
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JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

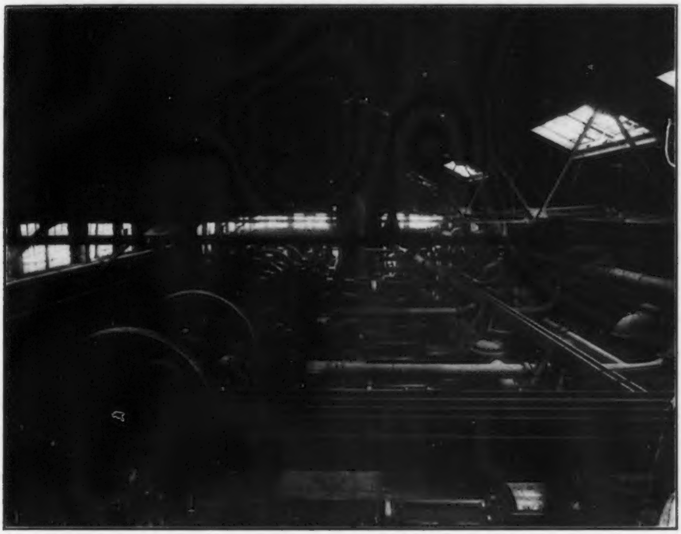


FIG. 1.—AIR COMPRESSORS, MANHATTAN PLANT.

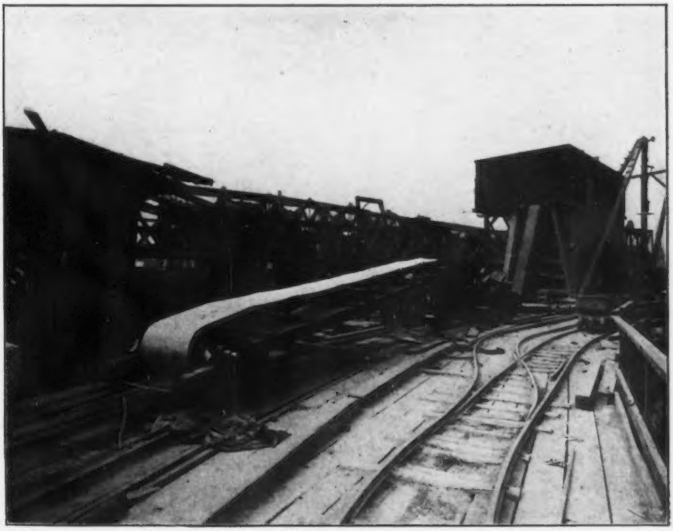


FIG. 2.—BELT CONVEYOR.

"The pipes necessary for air supply, ventilation, hydraulic and electric transmission, and other purposes shall be built into the bulkhead and provided with suitable connections. All pipes shall be standard, lap-welded.

"When a shield has been driven 500 ft. or more from the shaft, at least two bulkheads shall always be in use if compressed air is used.

"A safety screen, extending from the roof downward into the tunnel, of design approved by the Engineer, shall be maintained within 100 ft. of each working face, and others shall be built at intermediate points between the working face and the nearest bulkhead, if necessary, to maintain a chamber filled with compressed air along the tunnel roof and give access to the emergency lock. The galleries shall extend from the safety screen nearest the working face to the first bulkhead.

"The shields must be of ample strength and of the best materials, must be provided with hydraulic rams of sufficient power to move them along the alignment laid down on the plans and profiles, and must have adequate arrangements for the rapid execution of the work and for the safety of the men employed therein. The Contractor will be required to make use of the most effective devices in the construction and operation of the shields.

"Detailed plans and specifications of the shields, hydraulic presses, fittings, and other appliances must be submitted to the Chief Engineer before the construction of the shields is begun, and must be modified or amended, if required by him, and then built in exact accordance with the plans in every respect. Such submission of plans to the Chief Engineer shall in no way relieve the Contractor from his responsibility for carrying out the work embraced in the contract."

These specifications were a great help to the contractors in bidding, and also in deciding what plant should be installed.

The original plant fulfilled these requirements, but the porous material overlying the tunnels needed more air than specified, and the plant was increased.

Air Compressors.—In endeavoring to select the best air compressor for continuous night and day service, plants erected by the various manufacturers, where available, were examined, and indicator cards of the steam and air cylinders were taken, and, where plants were located too far away, indicator cards were submitted for inspection.

After studying their relative merits, it was decided to adopt the Ingersoll-Rand air-moved valve, on account of the larger area and free opening for inlet and discharge, and the reduced clearance spaces. This was chosen in preference to other types of inlets, with poppet dis-

charge valves, as a high piston speed was necessary on account of the limited area for plant installation at the disposal of the contractor.

This choice was amply justified, especially when the manufacturers replaced the original cast-steel valves by oil-treated steel forgings, which were very successful, and never had to be replaced during four years' operation.

One objection, in addition to the usual ones advanced, which influenced the decision against Corliss inlet valves was that, in compressors using such valves, the point of opening or inlet is fixed, whereas it ought to vary with the final discharge pressure, and as the pressure required in the tunnels and caissons called for engine-room pressures varying from 50 lb. per sq. in. downward, a fixed point of inlet was not desirable.

The air which is compressed in the clearance space expands to atmospheric pressure before a poppet valve will lift, but, with Corliss valves, if the inlet is set at a point in the stroke before the clearance air expands to atmospheric pressure, there is a puff of air outward, and, if the Corliss inlet valve does not open until after the compressed air in the clearance space has expanded below atmosphere, there will be a sudden inrush of air. In both cases energy is lost.

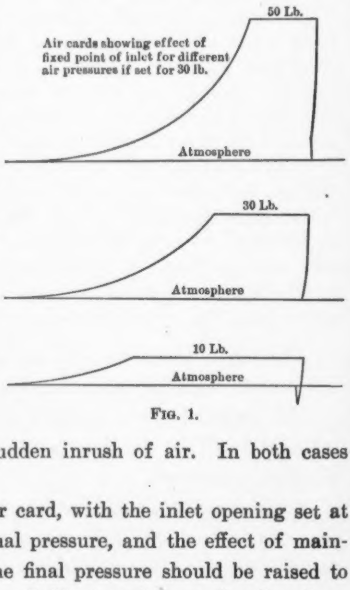


Fig. 1.

In Fig. 1 is shown a typical air card, with the inlet opening set at the correct position for a 30-lb. final pressure, and the effect of maintaining it at the same point, if the final pressure should be raised to 50 lb. or reduced to 10 lb. This is well illustrated on cards taken from the electrically-driven Corliss inlet compressors shown later. In most high-speed air compressors fitted with mushroom or poppet valves, a small loop is evident on the air cards, because a slight vacuum must be present before the inlet valve is drawn inward. With careful adjustment, the air-moved valves can be set so that there is no loop at a

certain speed, but if the engine runs at a different speed a slight loop occurs, as will be shown later on actual air cards.

In determining the size of units to be selected for the low-pressure air work, on laying out alternative plants based on different sizes of units, it was found that the most convenient size for the site available was a 5 000-cu. ft. per min. machine. The duplex compound Corliss condensing type — supplied by the Ingersoll-Rand Company — was selected, with steam cylinders 16 and 34 in. in diameter, and two air cylinders 26½ in. in diameter with a 42-in. stroke. The steam valves are of the Corliss release type with vacuum dash-pots. The air-valves are of the positive, pneumatically-operated type (Fig. 2), with two intake valves, and two discharge valves at each end of the air cylinder.

Each valve is 7 in. in diameter, giving a clear opening of 13.9% of the cylinder area at each end, which gives the air a speed of 7¼ times that of the piston provided the valve lifts one-quarter of its diameter from the seat. At 100 rev. per min. the piston speed was 700 ft. per min., and the speed of the air through the valves was 5 000 ft. per min. It was found that, in order to maintain perfect indicator cards, the valves need not lift the full quarter diameter.

They are all direct-lift valves, each with a central stem coming out through the cylinder head and carrying a piston which works in a small cylinder mounted on the head. These cylinders or dash-pots have the double function of operating the valves and of cushioning to prevent pounding and noise. The discharge valves are guided in the solid metal of the head and the inlet valves are guided in sleeves which are integral with the inserted valve seats, so that all the valves must seat true. The inlet valve has a spring-steel ring snapped into a recess around it, which prevents the valve from being sucked into the cylinder if the stem should break. The valves and appurtenances are interchangeable, and are easily removable.

At the side of the air cylinder is mounted a valve chest which has a flat seat and a sliding valve, the stem of which has on it a sliding sleeve connected by a rod to a horizontally-vibrating lever which receives its motion from the main piston-rod coupling. The motion of this sleeve, therefore, is coincident in time and direction with that of the main piston, but it only moves the valve rod a short distance at each end of the stroke, when it strikes adjustable collars on the stem. The ports at each end of the chest are connected to the outer ends of

the valve-operating cylinders. No air pressure is required when starting the compressor, the inlet valves being moved both ways by the air passing through them. As the pressure accumulates when the compressor begins to work, the valves are under full control after a few strokes.

The arrangement as described applies to the low-pressure cylinder. Supposing the compressor to be in full operation and the compressor piston at the end of its stroke, as it starts away from the cylinder head, the action of the sliding valve supplies air to the outer ends of the inlet-valve cylinders and the valves are opened. As the compressor piston moves forward, the sliding valve is brought to a central position by a spring, and the air is discharged from the valve-operating cylinders without moving the valves. When the compressor piston reaches the other end of its stroke, the sliding valve is moved again, air is admitted to the other ends of the valve cylinders, and the inlet valves are closed.

Connected with the inner ends of the discharge-valve cylinders are pipes opening into the compressor cylinder, so that, as the compressing piston advances and the pressure rises, the same pressure appears in the valve-operating cylinders, tending to open the valves. This is prevented by the normal pressure which is on the backs of the discharge valves until this pressure is overcome by the combined pressure in the compressor cylinder and the valve-operating cylinders, when the valves at once fly open, and the compressed air begins to flow into the discharge passage. Each valve cylinder has a port and a pipe tapped into it, and, as soon as the piston has moved a short distance, this port is uncovered, the pressure in the valve cylinder is exhausted, and the valve is cushioned or steadied in its movement by the air in the outer end of the cylinder. As the main piston passes on, it covers the pipe opening, and, when the piston reaches the end of its stroke and the sliding valve is moved again, air is admitted to the valve-operating cylinders and the valves are free to close. The pipe from the chest is led into the main intake to prevent noise from the discharged air.

The air used for operating these valves was reduced to about one-third of the discharge pressure of the compressor, and some adjustment of the openings controlling the air supplied to these small cylinders was necessary by the operating engineers before perfectly smooth running was attained, but, when the adjustment was made, the valves dropped to their seats with practically no noise. The inlet valves re-

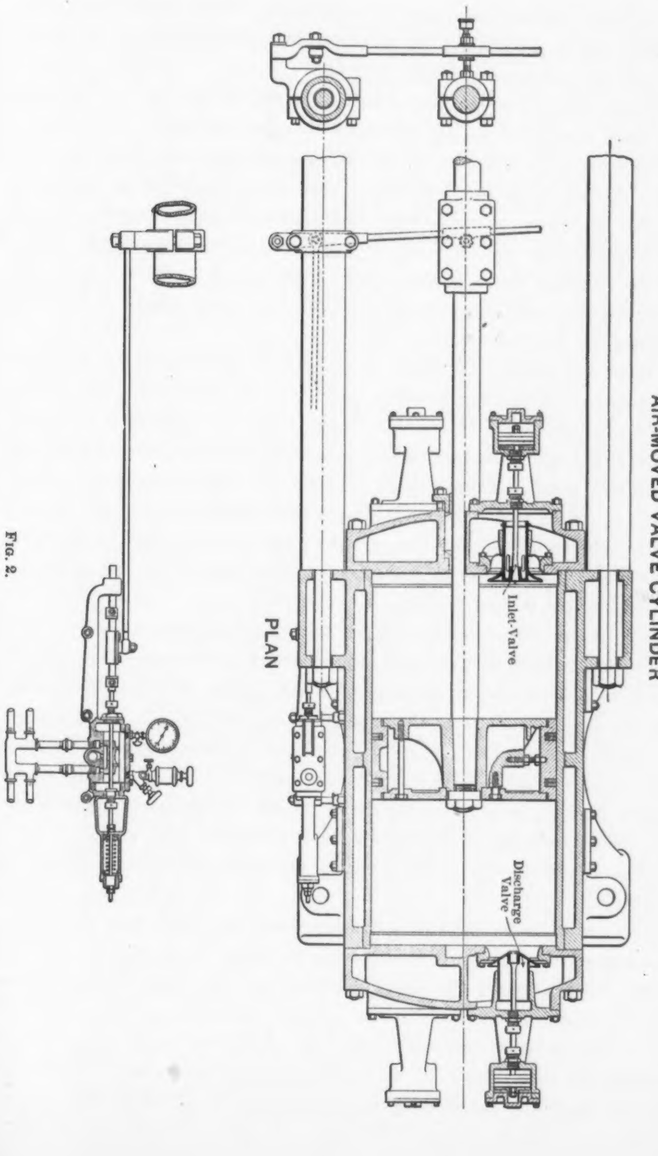


FIG. 2.

quired about six-tenths of 1%, and the outlet valves about three-tenths of 1%, or say, in all, 1% of the total free air compressed to operate them, if no leakage occurred.

The steam end of the air compressors was compound Corliss, with trip-gear controlled by the governor on each cylinder. In order to maintain a high economy at speeds varying from 50 to 125 rev. per min., the governor was fitted with a variable-speed device composed of two cast-iron saucers with their concave surfaces facing each other; the outer one, driven by a belt from the main shaft of the engine, engages three leather-lined rollers which in turn engage the inner saucer, sufficient pressure for friction drive being obtained by a spring on the spindle.

With the axis of the three leather-lined rollers at right angles to the axis of the saucers, the two saucers go at the same speed, but in opposite directions. If the rollers are tilted, so that they roll on a larger diameter of contact on one saucer than on the other, a different speed will result. These rollers are held in a triangular frame which does not rotate, and it is possible by a hand-wheel to alter the inclination of the rollers so that the speed of the governor can be changed. This allows the engine to run at a variable speed, with the governor floating in its critical position.

The steam cylinders and intermediate receiver were steam-jacketed, and a Cochrane steam separator was mounted on the stop-valve. Steam was admitted at a boiler pressure of 150 lb. per sq. in., and the exhaust was carried to condensers at about 26 in. of vacuum.

Table 1 gives a fair idea of the efficiency of these low-pressure units for seven compressors on the Manhattan side. From this it would appear that the mechanical efficiency of the machine is a little better than 90%, and the volumetric efficiency about 96 per cent.

Fig. 3 shows typical steam and air cards for the low-pressure machines.

On a test made for steam consumption, the result was 14.2 lb. of steam per i.h.p. per hour, compressing up to 30 lb. per sq. in.

In order to cover the demand of the specifications for 25% spare plant, a combination machine was designed which could be used either as a high-pressure machine for rock drills, or as a low-pressure machine for tunnel air. It had the same steam end as the low-pressure engines, but was fitted with two low-pressure cylinders 22¼ in. in

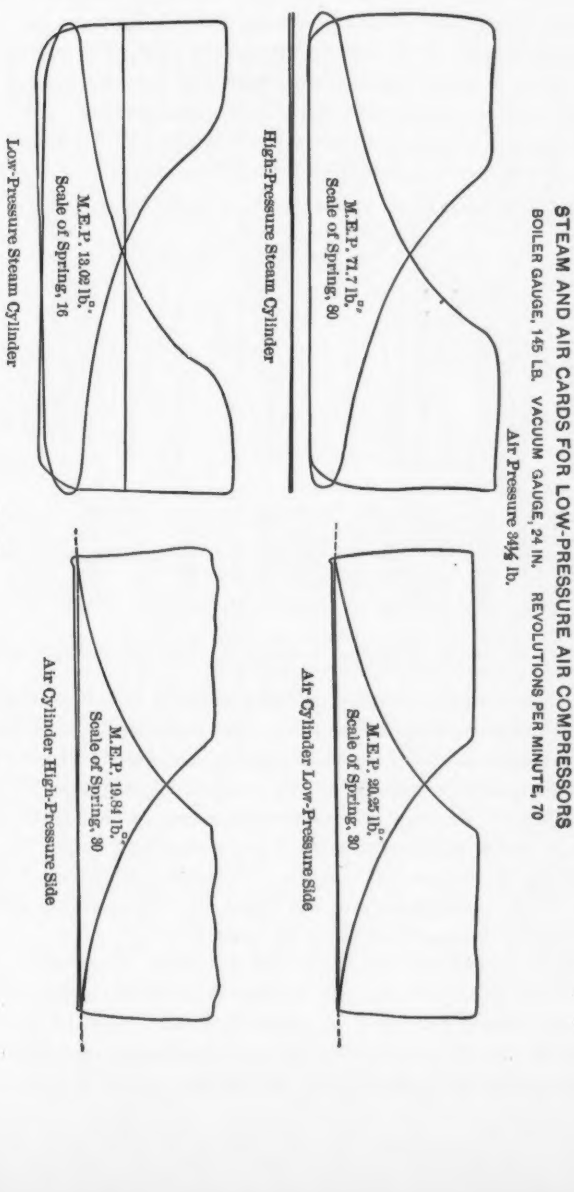

STEAM AND AIR CARDS FOR LOW-PRESSURE AIR COMPRESSORS
BOILER GAUGE, 145 LB. VACUUM GAUGE, 24 IN. REVOLUTIONS PER MINUTE, 70
Air Pressure 34½ lb.
M.E.P. 71.7 lb.
Scale of Spring, 80
High-Pressure Steam Cylinder
M.E.P. 13.02 lb.
Scale of Spring, 16
Low-Pressure Steam Cylinder
M.E.P. 20.25 lb.
Scale of Spring, 30
Air Cylinder Low-Pressure Side
M.E.P. 19.84 lb.
Scale of Spring, 30
Air Cylinder High-Pressure Side

Fig. 3.

diameter, and two high-pressure cylinders 15½ in. in diameter. Running as a low-pressure machine, with all four air cylinders in operation, it had a capacity of 5 000 cu. ft. per min., and, if it was desired to run it as a simple high-pressure machine, the two low-pressure cylinders could be disconnected and it could then compress 1 568 cu. ft. of free air, up to 90 lb., with atmospheric intake, and 6 899 cu. ft. to 140 lb., with an intake pressure of 50 lb. per sq. in.

TABLE 1.—RESULTS OF TESTS OF SEVEN COMPRESSORS AT THE MANHATTAN PLANT.

Engine No.	Diameters of steam cylinders, in inches.	Air Cylinders. Number.	Air Cylinders. Diameter, in inches.	Stroke, in inches.	Revolutions per minute.	Cubic feet of free air compressed per minute.	Air pressure, in pounds.	Isothermal horse power.	Adiabatic horse power.	Relation: Isothermal / Adiabatic.	Steam: Indicated horse power.	Air: Indicated horse power.	Efficiency: Isothermal horse power / Air, Indicated horse power.	Mechanical efficiency: Air, Indicated horse power / Steam, Indicated horse power.	Volumetric efficiency.
1	16 and 34	2	26½	42	70	3 569	35	278.8	339	82.0	376	332	84%	88.5%	96
2	16 and 34	2	26½	42	72	3 671	37½	298.0	367	81.5	491	361.5	83%	90.0%	96
3	16 and 34	2	26½	42	65	3 314	36	262.8	321	81.8	349	318	82.6%	91.0%	96
4	16 and 34	2	26½	42	75	3 824	36½	306.0	373	81.7	407.5	376	81.4%	92.0%	96
5	16 and 34	2	26½	42	65	3 314	37	266.8	327	81.6	351	318	84%	90.5%	96
6	16 and 34	2	26½	42	85	4 324	36	343.6	420	81.8	455	419	82%	92.0%	96
7*	16 and 34	2 2	15½ 22¼	42	98	5 060	92	640.0	744	86.2	865	779	82.2%	90.0%	97.2

* Engine No. 7 was operated as a high-pressure compressor, with two 15½-in. cylinders in combination with a low-pressure machine. See Fig. 4.

Although heavily overloaded, it was possible to run these machines as independent two-stage compressors. The low-pressure cylinders, of course, were too small for the most efficient arrangement of two-stage, and would require a diameter of 26½ in., but, by admitting an additional supply of air from the tunnel compressors to the high-pressure end of the machine, it was possible to get a very large output from it.

In Table 1, Engine No. 7 is the combination machine. Further details of its performance are shown on Fig. 4, operating with a low-pressure compressor as a two-stage machine.

Each air compressor was fitted with a vertical low-pressure aftercooler, 57 in. by 14 ft. 6 in., each having 920 sq. ft. of cooling surface, fitted with tinned navy-mixture brass tubes and Tobin bronze tube plates. The air from each compressor was discharged into individual low-pressure air receivers, 4 ft. 6 in. in diameter and 12 ft. high.

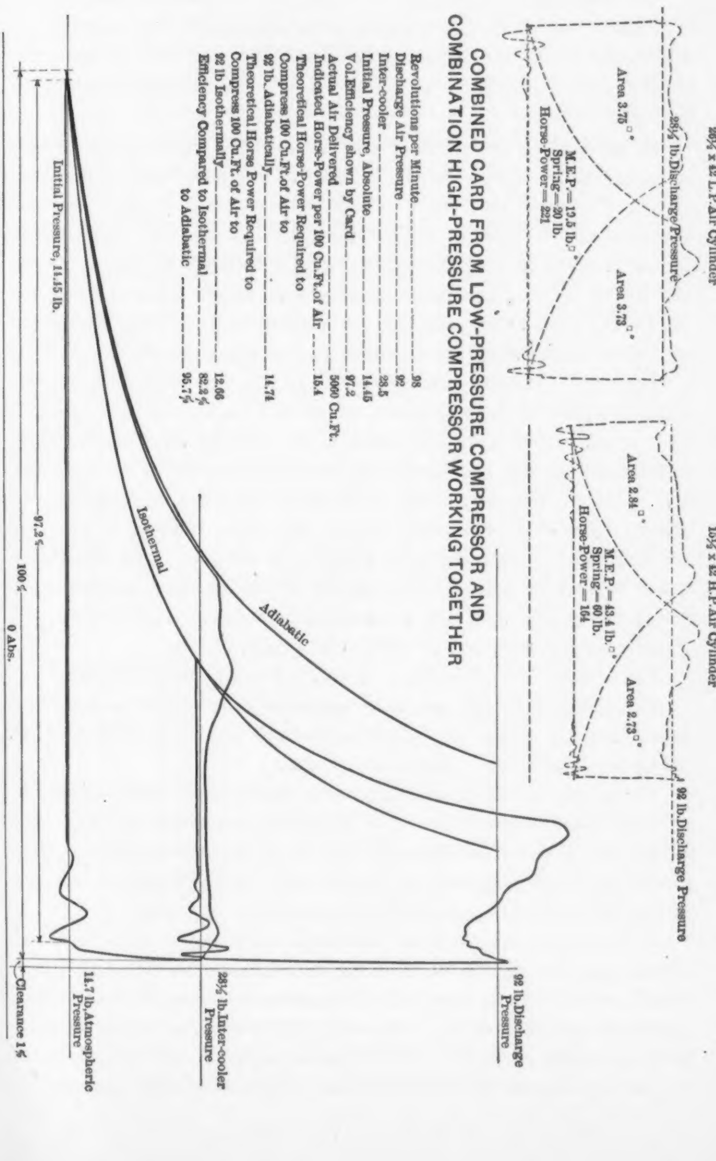

26½ x 42 L.P. Air Cylinder
28½ lb. Discharge Pressure
Area 3.75□"
M.E.P. = 19.5 lb.□"
Spring = 20 lb.
Horse-Power = 221
Area 3.73□"
15½ x 42 H.P. Air Cylinder
92 lb. Discharge Pressure
Area 2.84□"
M.E.P. = 43.4 lb.□"
Spring = 60 lb.
Horse-Power = 164
Area 2.73□"
COMBINED CARD FROM LOW-PRESSURE COMPRESSOR AND
COMBINATION HIGH-PRESSURE COMPRESSOR WORKING TOGETHER
Revolutions per Minute 98
Discharge Air Pressure 92
Inter-cooler 28.5
Initial Pressure, Absolute 14.45
Vol. Efficiency shown by Card 97.2
Actual Air Delivered 5000 Cu.Ft.
Indicated Horse-Power per 100 Cu.Ft. of Air 15.4
Theoretical Horse-Power Required to
Compress 100 Cu.Ft. of Air to
92 lb. Adiabatically 14.74
Theoretical Horse Power Required to
Compress 100 Cu.Ft. of Air to
92 lb Isothermally 12.66
Efficiency Compared to Isothermal 82.2%
to Adiabatic 95.7%
Adiabatic
Isothermal
Initial Pressure, 14.45 lb.
97.2%
100%
0 Abs.
92 lb. Discharge Pressure
28½ lb. Inter-cooler Pressure
14.7 lb. Atmospheric Pressure
Clearance 1%

FIG. 4.

The combination machines, acting as high-pressure compressors, were also fitted with a low-pressure after-cooler which was used as an inter-cooler when the machine was two-stage, and the air was discharged into a high-pressure air receiver, 60 in. in diameter and 14 ft. high.

In addition to the steam-driven, low-pressure machines, it became necessary at the Long Island City site to purchase two low-pressure, electrically-driven machines. These were supplied by the Laidlaw-Dunn-Gordon Company. Each compressor had two air cylinders, 31 in. in diameter with 42-in. stroke, with rotative inlet valves of the Cincinnati type. These were purchased in spite of the objection to the Corliss inlet noted previously, as they were to be used toward the end of the work, when the air pressure was almost constant.

They were designed for a speed of 75 rev. per min., with a rope-drive fly-wheel, 20 ft. in diameter, weighing 20 tons, and with fourteen 2-in. ropes. Horizontal after-coolers, of 1 000 sq. ft. each, were attached, and the air was discharged into air receivers 12 ft. high and 4 ft. 6 in. in diameter. They were driven by 600-h.p. Westinghouse motors, Type *CCL*, 440 volts, 3-phase, 25 cycles, running at 300 rev. per min., with a rope sheave 5 ft. 2 in. in diameter. The motors received current from three transformers of 375 kw. each, oil-insulated, and water-cooled, receiving alternating current at 11 000 volts and transforming it down to 440 volts of 25 cycles, 3-phase.

Fig. 5 shows the efficiency of these machines from actual tests.

The great drawback to these electrically-driven air compressors is that there is no way of regulating the volume of air discharged, as the speed of the motor cannot be changed.

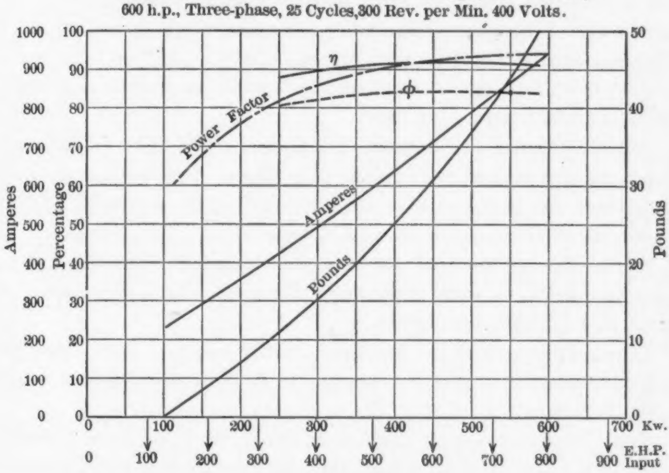
The usual method of operating them was to open them out on two or more tunnels requiring more than their combined capacity, and adjust the volume of air by means of one of the steam engines. They worked very well and gave no anxiety, and without them one or more of the tunnels would have had to shut down.

As stand-by high-pressure machines, when the combination machines were on low-pressure duty, two Class *HC*, Ingersoll-Rand, duplex, simple, steam, two-stage air compressors were purchased, with two steam cylinders 16 in. in diameter, and air cylinders 16¼ and 25¼ in. in diameter and 16-in. stroke, and a capacity of 1 205 cu. ft. of free air per minute for each machine, for the Manhattan site.

On the Long Island City side, where not so much rock was encountered, while the combination machine was likely to be used on low-pressure duty, one Imperial Ingersoll-Rand, duplex, simple, steam, two-stage air compressor was purchased, with two steam cylinders 16 in. in diameter, and air cylinders 15 and 25 in. in diameter and 20-in. stroke, and steam and air pressure of 100 lb. per sq. in., with a capacity of 1 700 cu. ft. of free air per minute.

EFFICIENCY CURVES
FOR ELECTRICALLY-DRIVEN AIR COMPRESSORS

No. 2, Laidlaw-Dunn-Gordon, Duplex, Electrically-Operated, Rope-Driven Compressor. Westinghouse Type, C.C.L. Motor, 600 h.p., Three-phase, 25 Cycles, 300 Rev. per Min. 400 Volts.



η Mechanical Efficiency $= \frac{\text{Indicated Horse Power}}{\text{Power at Motor Sheave}}$

ϕ Efficiency $= \frac{\text{Indicated Horse Power}}{\text{Electrical Horse Power}}$

Motor Efficiency 92% from one-half to Full Load
Average Volumetric Efficiency, 95.7%
Revolutions of Compressor per Minute = 75
Diameter of Cylinders = 31 in.; Stroke, 42 in.

FIG. 5.

For starting up the headings at the East Avenue site, two Ingersoll, straight-line air compressors were purchased, with steam cylinders 18 in. in diameter, air cylinders 18¼ in. in diameter and 2-ft. stroke. At 94 rev. per min., with a steam and air pressure of 90 lb., each had a capacity of 656 cu. ft. of free air per minute.

As there were ultimately two electrically-driven air compressors on the Long Island side, and six low-pressure machines and one combination machine on each side of the river, and as these machines were guaranteed to run at 125 rev. per min. continuously for 24 hours, the maximum free air capacity of all the machines, including the high-pressure compressors, amounted to 102 922 cu. ft. per min. A general view of the Manhattan plant is shown on Fig. 1, Plate I.

Boiler Plant.—Steam at a boiler pressure of 150 lb. was generated in twelve Stirling water-tube boilers, six on each side of the river, each having a capacity of 500 b.h.p, with 10 sq. ft. of heating surface per horse power, and ¼ sq. ft. of grate surface per horse power. The grates were 8 ft. deep. Each boiler had three steam drums, 42 in. in diameter and 16 ft. 11½ in. long, and one mud drum, 42 in. in diameter and 15 ft. 10 in. long. A manhole was fixed in one end of each drum. The tube plates were ⅝ in. thick.

Each boiler had 405 lap-welded, mild-steel tubes, 3¼ in. in diameter, expanded into reamed holes in the tube plates. The steam outlet was 8 in. and the feed and blow-off valves 2½ in. in diameter. Safety valves, 4½ in. in diameter, were set to blow off at 155 lb. per sq. in.

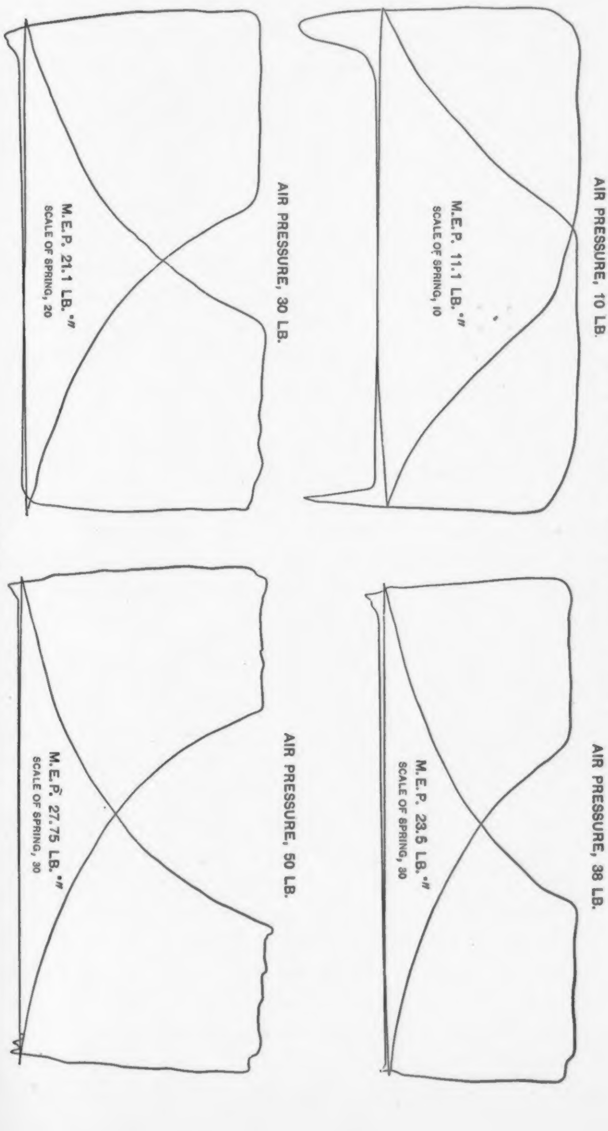
Hydraulic-turbine tube cleaners were supplied with the boilers, and were found to work much more efficiently with high-pressure air than with high-pressure water.

The grates were of the McClave shaking variety. Each boiler occupied a space 19 ft. 9½ in. wide and 18 ft. 3 in. deep, with a height of 20 ft. 11¼ in.

The brickwork was of high-grade fire-brick, 9 in. thick. Before putting the boilers under steam, they were tested to a water pressure of 225 lb. per sq. in.

Each boiler had an independent steel stack, 54 in. in diameter, rising to a height of 100 ft. above the grate level. The thickness of the metal varied from $\frac{5}{16}$ in. for the bottom strakes to ¼-in., $\frac{3}{16}$-in., and No. 8 plates at the top.

The boilers were guaranteed to evaporate 8.7 lb. of water per pound of dry coal having a heat value of not less than 12 000 B. t. u., and not more than 15% ash from and at 212° Fahr., with a pressure in the ash-pit of not less than + 2 in. and a draft at the damper box of 0.75 in. This result was to be obtained with either No. 1 or No. 2 buckwheat anthracite coal. In testing the boilers, they were found



INDICATOR DIAGRAMS
TAKEN FROM NO. 2 LAIDLAW ELECTRIC COMPRESSOR,
LONG ISLAND CITY POWER-HOUSE.

FIG. 6.

to exceed this efficiency. The outline drawings, Plate II, show the general arrangement of these boilers.

In computing the boiler capacity necessary, it was estimated originally, before finally deciding on the whole plant, that, on each side of the river, the indicated horse power shown in Table 2 would be developed.

TABLE 2.

	Indicated horse power.	Pounds of steam per indicated horse power-hour.	Pounds of steam per hour.
Electrical plant	580	25	14 500
Air compressors	3 250	15	48 750
Hydraulic, 6 000 lb. pressure	112	25	2 800
Hydraulic, 1 000 lb. pressure	90	25	2 250
Total	4 032		68 300

On the basis of 8 lb. of water evaporated per pound of coal, this would represent 8 500 lb. of coal per hour. Assuming 4 lb. of coal per boiler horse power, the capacity would be 2 125 + (25% spare plant = 531) = 2 656; say, five boilers at 500 h.p., or 2 500 b.h.p.

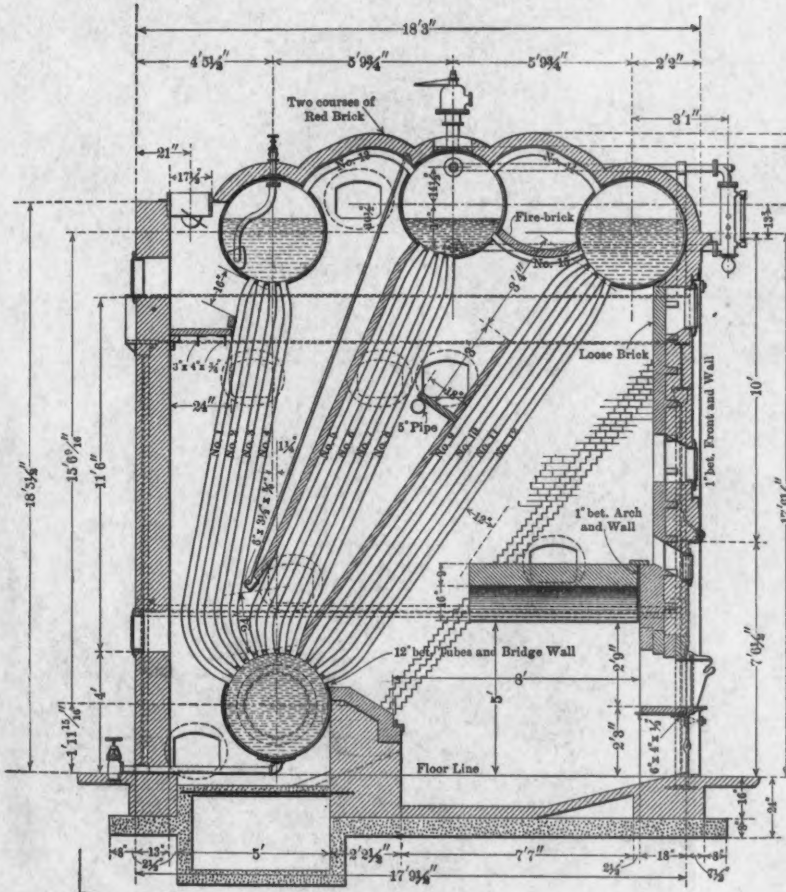
As a check on this, 5 sq. ft. of heating surface will give 1 i.h.p., easily. At sea, with forced draft, it has been done on 2 sq. ft., but say 5, for easy steaming; then the heating surface = 4 032 i.h.p. × 5 = 20 160 sq. ft.; taking 10 sq. ft. per boiler horse power = 2 016 b.h.p., or four units of 500 b.h.p. and one spare, making five of 500 b.h.p. Ultimately, it became necessary to increase the compressor plant, and a sixth boiler was added on each side of the river.

Forced-Draft Apparatus.—Boilers were furnished with closed ash-pits into which entered, for each boiler, two 12 by 36-in. air ducts, from a duct 3 ft. 3 in. by 3 ft. 10 in. Two Buffalo Forge Company's fans were supplied for each plant of five boilers, and another fan was added for the sixth boiler. Each fan was 6 ft. 6 in. in diameter, 30 in. wide at the periphery, 39 in. wide at the center, and had eight blades, driven by a direct-connected, 7 by 8-in., vertical engine above the shaft. The guaranty of the fans is shown in Table 3.

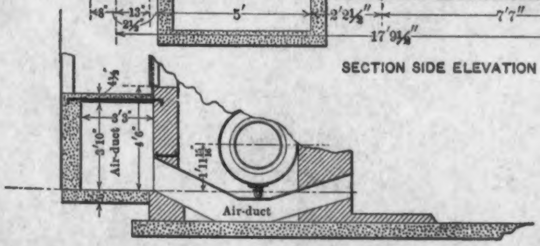
The fans were controlled by regulating valves on the steam pipe; these opened when the steam pressure fell, and allowed the fans to speed up.

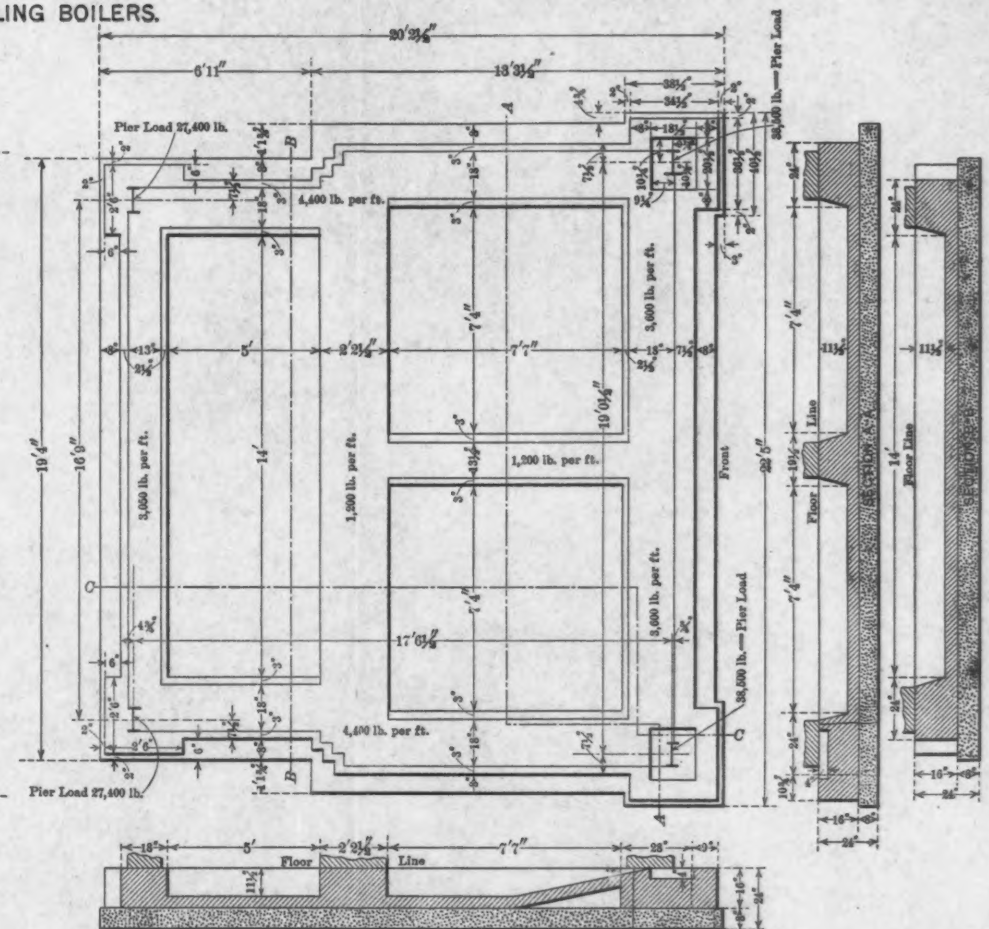
In addition to the twelve Stirling boilers, there were on the works

STIRLING BOILERS.



SECTION SIDE ELEVATION





SECTION C-C
FOUNDATION PLAN

NOTE:-
Column Footings to be of Hard Red Brick carefully laid and bonded.

at East Avenue, for driving the headings, four 100-h.p. boilers, of the locomotive type, supplied by the Nagle Boiler Works.

TABLE 3.

Revolutions per minute.	Total pressure, in ounces.	Delivery, in cubic feet.	Indicated horse power.
253	1	27 900	17
284	1¼	31 392	25
313	1½	35 000	33
360	2	39 800	48

The steam per indicated horse power was not to exceed 40 lb.

These boilers were for supplying steam to the two straight-line compressors already described, and also for driving a fan engine for ventilation, as well as the pumps in the shaft, and the steam derricks. They were of the standard locomotive type, each with a grate 60 in. long and 54 in. wide, and had 88 tubes, 3 in. in diameter and 168 in. long, giving a heating surface of 1 094 sq. ft. Each boiler had an independent smokestack, 30 in. in diameter and 46 ft. high.

These boilers were tested to 150 lb. pressure, and were worked at 90 lb. Other smaller boilers on the different sites were used for steam derricks and heating purposes.

Steam Pipes.—An 8-in. steam pipe led from each boiler into a 12-in. header each end of which joined a 10-in. line led around the power-house to form a loop.

For each compressor a 6-in. branch was taken from the 10-in. header, and, on one side of the 6-in. branch, a 10-in. gate-valve was placed in the header and a 6-in. gate-valve on the branch. Gate-valves were also placed on one side of each 8-in. boiler branch in the main 12-in. header. In this way, if a joint gave out anywhere, it was always possible to repair it after shutting down only one boiler or one compressor.

Independent loops were formed on the steam lines for supplying electric generators, hydraulic pumps, and the auxiliary machinery. Expansion joints were formed by easy loops in the main headers, and Vanstone joints were used in pipes 8 in. in diameter and greater.

The steam pipes were supplied and erected by the Pittsburgh Valve and Foundry Company. This company also fitted the exhaust-steam, compressed-air and water piping, which will be described later, as well as the oiling arrangements.

Each boiler was fitted with a non-return stop-valve, so that, in the event of a boiler tube giving way, the whole battery would not be emptied of steam, but the valve would close when the pressure in the damaged boiler becomes less than that in the main pipe. This type of non-return, crown-head valve was first adopted in battleship construction on account of the danger of a boiler being pierced by a shell, and is now used almost everywhere in boiler plants.

WHEELER'S ADMIRALTY SURFACE CONDENSER

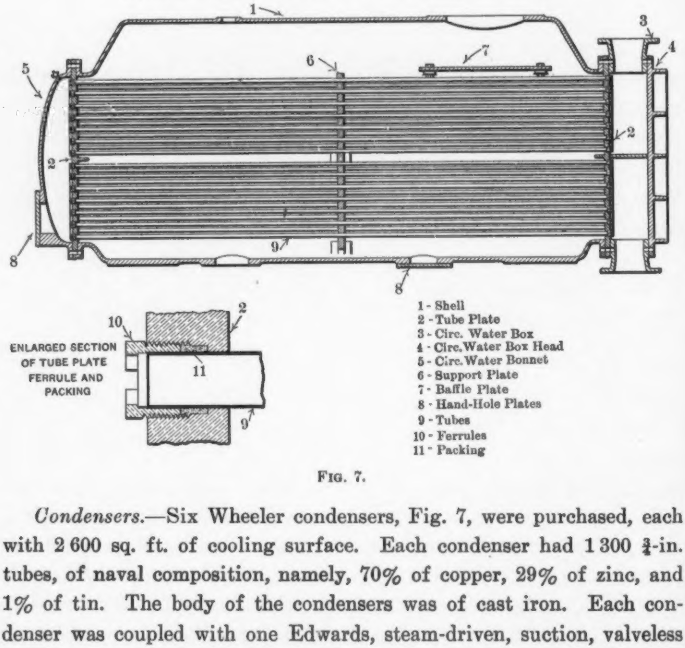


FIG. 7.

Condensers.—Six Wheeler condensers, Fig. 7, were purchased, each with 2 600 sq. ft. of cooling surface. Each condenser had 1 300 $\frac{3}{4}$-in. tubes, of naval composition, namely, 70% of copper, 29% of zinc, and 1% of tin. The body of the condensers was of cast iron. Each condenser was coupled with one Edwards, steam-driven, suction, valveless air-pump, Fig. 8, each having a 7-in. steam cylinder and an 18-in. air cylinder of 12-in. stroke. They were of the double fly-wheel type, single-acting, and dispensing with all suction valves.

Each condenser and pump was guaranteed to be of ample capacity to maintain a vacuum of 27 in. when each unit was caring for 25 000 lb. of steam per hour, with a sufficient quantity of circulating water at 60° Fahr., and 30-in. barometer. Each air-pump was guaranteed to

use not more than 10 h.p., and to consume not more than 60 lb. of steam per i.h.p.

In computing the capacity of the condensers necessary for handling the plant, it was assumed that each square foot of surface would take care of 10 lb. of steam per hour, and, as the evaporation from five boilers amounts to 78 000 lb. of steam, three condensers would each

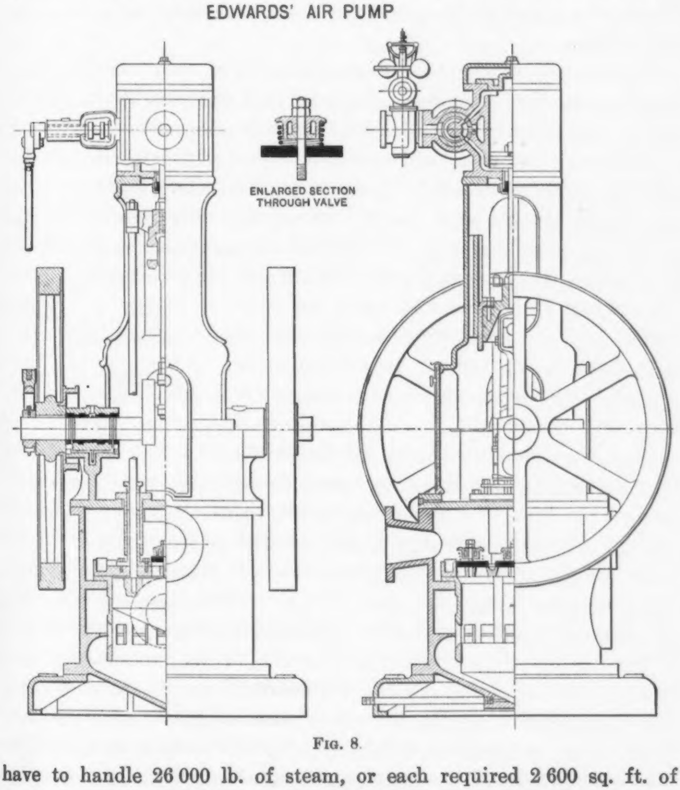


Fig. 8.

have to handle 26 000 lb. of steam, or each required 2 600 sq. ft. of cooling surface. Ultimately, it was decided to install three condensers on each plant of this capacity, and it was found to be ample for the purpose of maintaining a vacuum of 26 in.

In the event, however, of the condensers going out of action or being flooded with steam, and the pressure rising above that of the

atmosphere, two 18-in. atmospheric relief valves were fixed, so that the exhaust steam could pass to the atmosphere.

Each air compressor had a 14-in. exhaust which connected with the main exhaust header. The header was 20 in. in diameter, and had an expansion joint. It connected with each condenser by an easy bend through a 20-in. gate-valve, and reduced from 20 in. to 18 and 14 in. at each end of the power-house, the condensers being located at the middle.

On account of the East River water being used for circulating purposes for the condensers, and from past experiences through the failure of condenser tubes by electrolytic or chemical action, it was decided to protect each condenser tube with a ferrule of zinc, so that the zinc could be attacked in preference to the tubes. The usual naval practice is to suspend sheets of zinc on the water side of the condenser, but ferrules of zinc on split brass tubing, called zincoids, Fig. 9, supplied by the Wheeler Condenser Company, can be placed in each tube where the water enters, and are very effective. So effective were these in neutralizing all corrosion that out of 7 800 tubes only 75 were replaced in four years' operation.

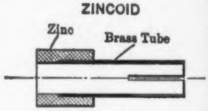


FIG. 9.

Coal Handling Plant.—On the Manhattan side, coal was unloaded from coal scows by a Ransome digger, dumped into 4-yd., steel, side-tip cars, standing on a weigh-bridge, and hauled along the upper staging by a small steam locomotive and dumped in the bunker.

On the Long Island side, it was possible to put in a more economical arrangement, and here the coal was hoisted from the coal scow by a clam-shell and dumped into a hopper from which it was shot into a steel, double-wing, side-dumping car of 24 cu. ft. capacity on a weigh-bridge. The car, on being pushed off the weigh-bridge, was caught underneath on the axle by a hook on a moving chain, and drawn up an incline, from the top of which it ran by gravity into the bunker; the wings of the car were opened automatically at any given point, and the coal dumped.

The car continued to move freely after dumping, and, passing over a pair of points at the end of the bunker, ran up a sharp incline, which brought it to rest and reversed the direction; it then returned down a side road on a down grade to the weigh-bridge.

A bunker with a capacity for 6 weeks' coal supply, on the basis of 600 tons per week, was erected on the Long Island City side, and, on the Manhattan side, where there was not as much room, 4½ weeks' supply was put in. These bunkers consisted of heavy timbers with tie-rods and diagonal bracing. The bottom of the bunkers was on the level of the firing floor, and while the bunkers were well filled the coal slid down on its natural slope to chutes within easy reach of the firemen, who fired by hand. When the supply got short, it was necessary to wheel the coal to the firemen in barrows. There is no doubt that mechanical stokers would have resulted in some economy, both of labor and of coal consumption, but the initial expense was too great for a temporary plant.

On the Manhattan side, the ashes had to be raked from the ash-pits and wheeled to bucket elevators set into the side of the bunker opposite the center boiler, the elevator raising them to a hopper above the upper staging, where they were shot into the 4-yd. coal cars and dumped into scows.

On the Long Island side, where the firing floor was wider, a 30-in. track was laid, and the ashes were loaded into 24-cu. ft., side-dump, steel cars, and hauled up an incline on the dock, where they could be dumped either into scows or cars.

When the boilers were being forced, it was a serious operation to remove the ashes from the ash-pits, and on several occasions, while the tunnels were making their biggest demand for air, they were allowed to accumulate until the grates were burned down. It was a very critical situation, and, after this experience, it would be well in future to mount boilers of this size high enough so that the ashes could be dumped into a hopper below without any danger of burning down the fire-bars.

Coal Consumption.—With five boilers in operation the biggest coal consumption at the Manhattan side for any one month was at the rate of 800 tons per week. This is equivalent to 17 lb. per sq. ft. of grate surface per hour for five boilers. According to the records kept, the average consumption was 2.8 lb. of coal per i.h.p. per hour for all machinery. The coal used on the Long Island side was No. 2 buckwheat; on the Manhattan side, where a greater demand was made on the plant, No. 1 buckwheat was used.

The coal on arrival was tested for its quality by sifting it through

standard screens. No. 1 screen had 2½ meshes per lin. in., or 6¼ meshes per sq. in.; No. 2 screen had 2.84 meshes per lin. in., or 8 meshes per sq. in.; No. 3 screen had 8 meshes per lin. in., or 64 meshes per sq. in. The class of coal supplied did not seem to be according to any fixed standard, nor could the coal merchants be persuaded to specify what was meant by the different grades, named No. 1, No. 2, and No. 3 buckwheat.

No. 1 buckwheat weighed generally 52 lb. per cu. ft. wet, and 49 lb. dry, retaining 70% on No. 1 screen, 15% on No. 2 screen, and 11% on No. 3 screen, with 4% dust. This fell as low as 65% on No. 1, and the dust rose as high as 9 per cent.

No. 2 buckwheat generally retained 8% on No. 1 screen, 23% on No. 2, and 65% on No. 3, with 4% of dust. At times it fell as low as nothing on No. 1 screen, and 10% of dust.

Calorific values were also taken, and generally showed from 11 500 to 12 900 B.t.u., with ash varying from 13 to 20 per cent. The ashes weighed about 46 lb. per cu. ft. wet, and 37 lb. per cu. ft. dry. The actual ash from the boilers was generally from 20% to as high as 30% with a combination of poor coal and inefficient firemen.

Hot Wells.—The condensed water, after being drawn from the condenser by the air-pump, was discharged into the hot well at the general temperature of about 105°, or equivalent to a vacuum of about 27 in. A pump, of the duplex piston type, 7½ by 7 by 12 in., with a stand-by of the same size, was controlled by a float in the hot well to discharge the condensed water into the feed-water heater and oil-separating plant through a 6-in. pipe.

The feed heaters—which were purchased before the oil separators were decided on—were of the Cochrane open type, the exhaust steam from the auxiliaries passing into it and coming in direct contact with the hot-well water. It would have made a better arrangement if a closed feed-water heater had been adopted, and if the feed water, after being purified, had passed through the coils of the closed feed heater with the exhaust steam passing outside them, but, as it was necessary to extract all the oil from the condensed steam, and as the Cochrane heaters were already on the ground, they were installed between the hot well and the oil separator, so that the oil from the auxiliaries might also be removed.

Oil Separators.—The feed-water purifying and oil-separating plant

was a combination of the Masson-Scott purifier, Fig. 10, with the Wilson automatic self-cleansing filter, Fig. 11.

The principle of the apparatus is to treat the oily water from the hot well with alumina-ferric, so that the oil is absolutely separated from the water, and, at the same time, the water is treated with such chemicals as may be necessary for getting rid of scale which might accumulate from the make-up feed. The apparatus consisted of two lead-lined mixing tanks, in one of which the alumina-ferric was dissolved, and in the other soda ash. From this tank the mixture was run into a tank large enough for 24 hours' supply.

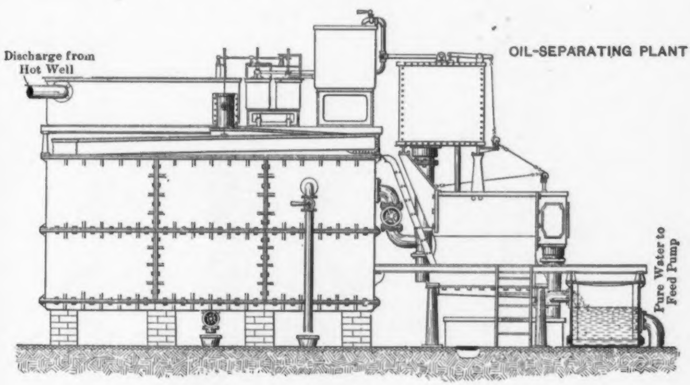


FIG. 10.

The hot-well water discharged into the chemical-regulating tank, which had three compartments. In the first compartment alumina-ferric flowed, in the second a mixture of soda ash, and in the third the hot-well water. A float in the third compartment controlled the outlets of the other two. If there was a large flow of hot-well water, the level rose and the float regulated the quantity of alumina-ferric and soda ash, which flowed with the hot-well water into a mixing trough, fitted with diaphragm plates in order that the ingredients in the water might be thoroughly mixed before entering the reaction tank—a large built-up cast-iron tank, fitted with three diaphragms. The water dipped under the first diaphragm, flowed up over the second, and down under the third, and then left the tank for the filter just under the water level.

The reaction tank was fitted with a large scum-cock, and, as the water flowed slowly under and over the diaphragms, oily matter rose to the surface and was blown off from time to time. The water then flowed through a regulating valve and into the sand filter, which was made in two distinct parts, each capable of taking care of 4 000 Imp. gal. per hour.

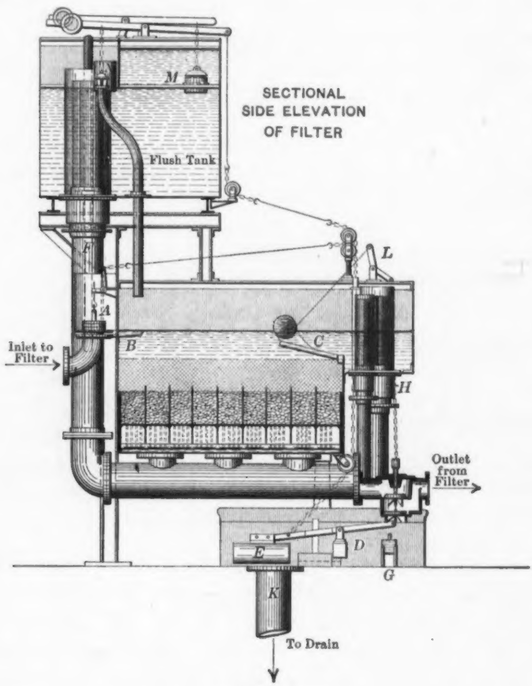


FIG. 11.

The filter, which was built up on cast-iron grids, consisted of a layer of about 9 in. of large pebbles, graduated from large to small, with 7 in. of sand on top. After the water passed through the filter, it was absolutely clear, but in passing through it left behind it a quantity of very fine light particles of oil.

The filtering medium becomes silted up by the impurities arrested from the water, thus preventing the passage of water through the

PLATE III.
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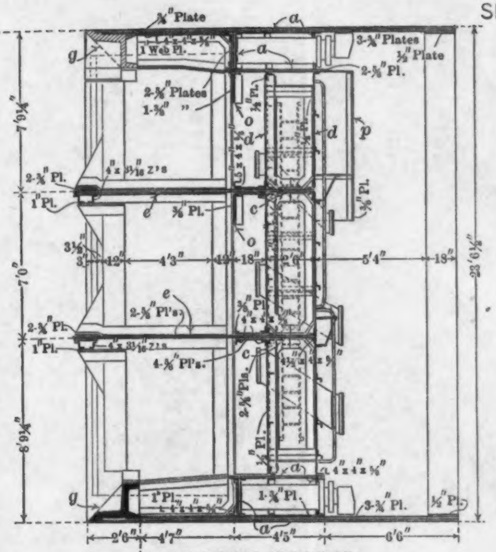
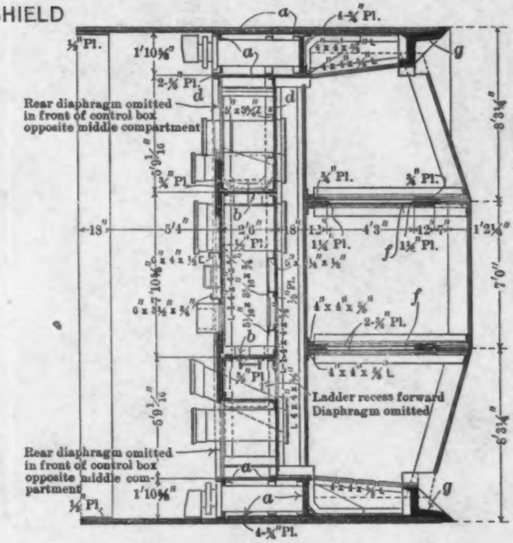
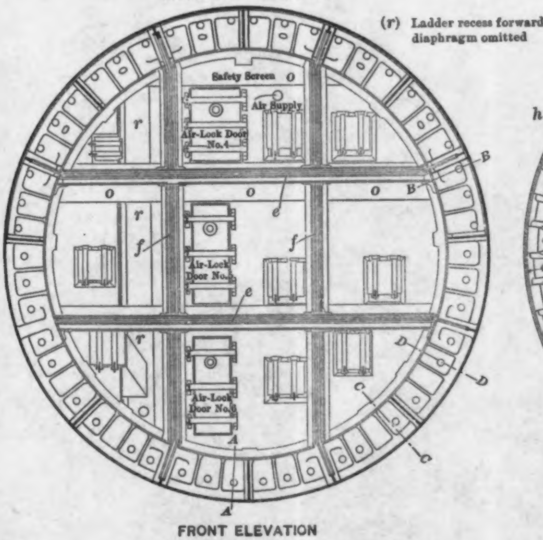
SHIELD



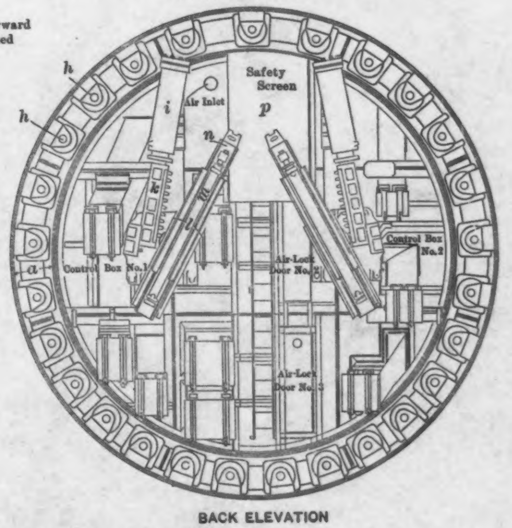
SECTIONAL ELEVATION



SECTIONAL PLAN



FRONT ELEVATION



BACK ELEVATION

medium, and causing it to accumulate until it reaches a certain level where it overflows a siphon which draws into a float chamber underneath a sufficient quantity of the water to raise a float. By means of chain connections with the float, the inlet and outlet valves are closed, and a large flushing tank overhead is opened, so that water in great volume is discharged under the bottom of the filter and upward through the filtering medium. The air in the pipes and in the cellular bottom beneath the filter bed is forced through the filtering medium by the down-rush of the water, and aerates and agitates it, and, being followed by the upward rising water, the whole filter is cleansed. The water above the medium rises rapidly, and a much larger siphon goes into operation and carries off the foul water to the sewer; the float chamber, emptying after the rush of water is over, allows the float to fall and resume operations. In order to prevent sand from being carried over into the sewer, a float-board along the front of the filter rises with the water, and, although it is sufficiently below the surface of the water to allow the impurities to pass freely from the filter, the sand which is heavier is prevented from being carried off. The feed water then passes into the feed tank.

Dr. J. W. Schlegel, analytical chemist, of Elmhurst, states that alumina-ferric—more properly called iron alum—is a double sulphate of potassium and iron, viz.: $K_2SO_4\ Fe_2\ (SO_4)_3 + 24H_2O$. This acts as a powerful astringent and coagulant, and causes the oil globules to coalesce and rise to the surface. The addition of carbonate of soda, if in large quantities, produces the following reaction: $K_2SO_4\ Fe_2\ (SO_4)_3 + 3Na_2\ CO_3 + 3H_2O = 2Fe\ (OH)_3 + K_2\ SO_4 + 3Na_2\ SO_4 + 3CO_2$, resulting in a voluminous gelatinous precipiate of ferric hydroxide enclosing or forming a nucleus for the oil globules and thus facilitating their separation.

If the chemical strength of the mixture is correct, the proper reaction takes place and the water filters clear. Should the make-up water not be sufficiently hard, that is, should it not have sufficient salts of lime to make a proper reaction, a little soda can be added. As the soda gives an alkaline reaction and the alumina-ferric gives an acid reaction, the quantities of each must be arranged so that the result is neutral in character. This can easily be ascertained by the use of litmus paper.

These oil separators were so effective that no boiler makers were

employed on the works, and only a few tubes in the twelve boilers had to be replaced.

The water in the feed tank generally stood at a temperature of about 165 or 170 degrees. From the tank it was taken by the boiler feed pumps, which were of the duplex type, 12 by 7 by 12-in. outside-packed, made by the Buffalo Forge Company. There were three of them for each plant, and one pump could take care of the water. There was a regulator on the steam pipe, so that, if all the boiler feed-valves were closed, the excess pressure of the discharge immediately shut off the steam. The boilers were fitted with Reliance gauge columns, which had a float, and, if the water in the boilers rose too high or fell too low, a whistle blew to warn the water tender. Each boiler was also fitted with Murray's automatic feed regulator, consisting of a copper float in a cast-iron box connected at top and bottom to the water columns; if the level fell below normal, a small needle steam-valve opened and admitted steam to the under side of a small piston which opened the feed-valve against the pressure of a spring. When the level rose, the steam-valve closed and the spring shut the feed-valve. These regulators worked very well.

Water tanks were erected with a sufficient capacity for 24 hours' supply, which required 65 000 gal. to take care of make-up feed, hydraulic power, grouting, men's rooms, and sanitation. On the Long Island side, two cedar tanks, 21 ft. in diameter and 15 ft. deep, were erected, and, on the Manhattan side, the same capacity was obtained by putting up seven tanks 11 ft. in diameter, as there was not room for the larger size.

Had tanks been built with sufficient capacity to keep the plant running without purifying the condensed steam and using it for the boiler feed, a capacity of 300 000 gal. additional would have been required.

The general oiling system of the power-house was arranged with separate tanks for cylinder oil and engine oil in the roof of the building, to which the oil was pumped under pressure and flowed through sight-feed lubricators to the different parts of the machinery. The oil that was saved was filtered and pumped back into the tanks. For the air cylinder, to commence with, a very fluid oil, flashing at 406° Fahr., was used, with success, but after the engine-room air pressure reached about 38 lb., light clouds of smoke formed in the tunnels like mist.

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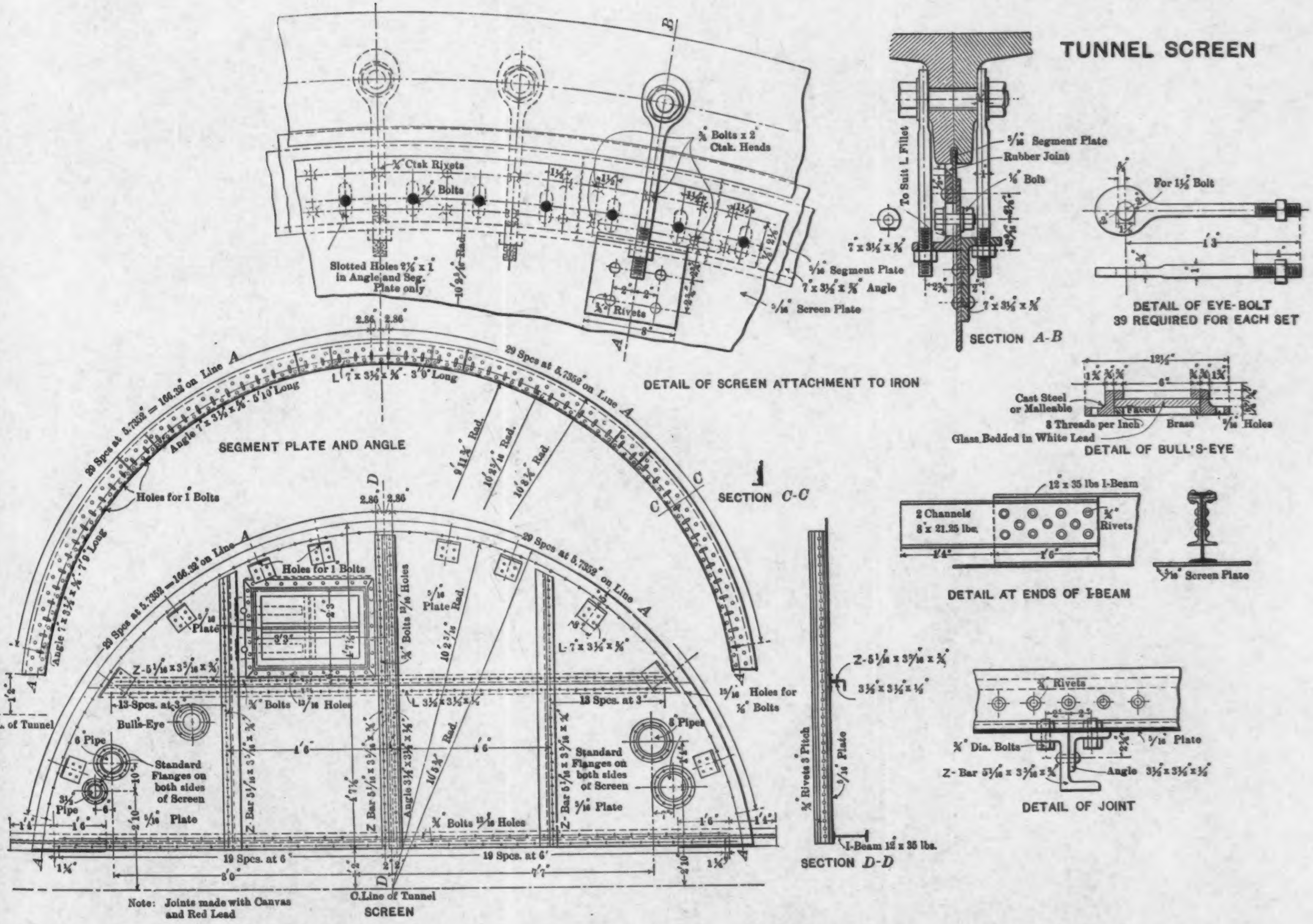
TUNNEL SCREEN



Charles M. Jacobs, M. Am. Soc. C. E., was consulted about this, and suggested that cheese-cloth be put over the ends of the discharge pipes in the tunnels to observe whether the mist was due to the oil, and in a few moments the cheese-cloth became black.

It was observed that if this oil was dropped on the outside of the hot-air cylinders, it went off into smoke, and the right-hand high-pressure cylinder of the combination machine at Manhattan exploded, pulling down the air piping with it. This was thought to be due to a spark created by friction in the cylinder igniting the vapor caused by the low-flash oil. Expert advice was obtained, through the Ingersoll Company, which called in Professor Denton, of Stevens Institute, and he advocated the adoption of a heavier oil. An oil named by the Vacuum Oil Company "600 *W* Mineral" oil, with a flash point of 550° Fahr., was then used, and from that time until the end of the work no trouble was experienced; but great care was taken to feed the minimum quantity required, which was small, and a careful examination of the air passages, made since the work was completed, showed only a very slight deposit of carbon from the heavy oil. Examinations were made for this purpose during operation, and the large mushroom-valves showed a deposit of about $\frac{1}{16}$ in. around their edges, but elsewhere the deposit was negligible.

Circulating Water.—The circulating water for the condensers, jackets, and after-coolers of the air compressors was drawn from the East River. On each side of the river was laid one 18-in. cast-iron suction line having a continuous-service foot-valve and a screen which could be raised and cleared without stopping the pumps. This 18-in. pipe was connected by two 10-in. branches with the centrifugals in the power-house used for the condensers. In addition, there was also a 10-in. cast-iron suction line with foot-valve and strainer for the air-cylinder jacket and after-cooler supply centrifugal pump which joined it with an 8-in. suction.

The discharge from the pumps was carried through a 24-in. earthenware pipe to the river.

The condenser centrifugals, of which there were two on each side, were 3 000-gal. Buffalo pumps, able to work against a head of 30 ft., including friction. Each pump was direct-connected to a double-vertical 7 by 5-in. double-acting engine of the enclosed type. They were guaranteed to discharge 3 000 gal. per min. at 350 rev. per min. with

an impeller 30 in. in diameter, and to consume not more than 40 lb. of steam per i.h.p.

These pumps discharged into a 16-in. cast-iron line, having a 12-in. connection to each condenser. For taking care of the jackets and after-coolers, one centrifugal pump having a capacity of 1 000 gal. per min. was fitted on each site. These were driven by 5 by 4-in. double-vertical, double-acting engines, and were guaranteed to work against a head of 40 ft. with an 8-in. suction and discharge. The indicated horse power was 17, giving an efficiency of 60% at 500 rev. per min. The guaranteed steam consumption was 43 lb. per i.h.p.

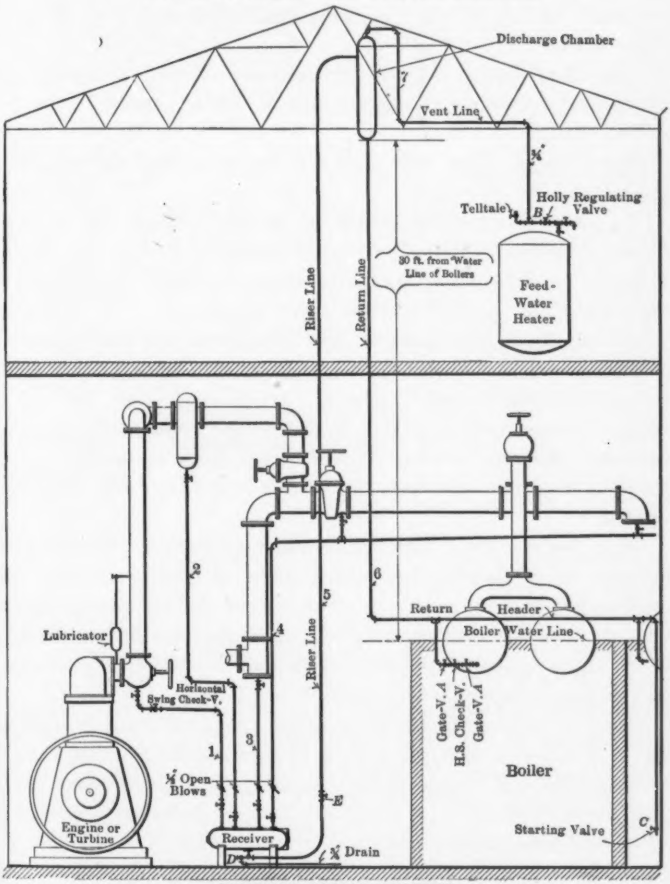
All impellers were of bronze, and the shafting was of Tobin bronze. A 10-in. cast-iron main was taken from the circulating pump, and branched off to each compressor, with 3½-in. supply pipes to the coolers and 2-in. supply pipes to the low-pressure cylinders. The combination low-pressure was fitted with 1½-in. and the high-pressure with 1¼-in. supply. All discharges from the jackets and coolers were visible, and fell into funnel waste pipes ½ in. larger in diameter than the supply pipes.

The city water supply from the cedar tanks was conducted to the power-house in a 3½-in. pipe, and this was connected as an emergency feed and for make-up feed, and also as emergency coolers and for priming centrifugal pumps. The discharge pipe from the feed pumps was 6 in. in diameter, branching to each check-valve with a 2½-in. pipe. Each feed line was fitted with a 2½-in. safety valve, and with 1½-in. connections for the use of the hydraulic tube cleaners, etc.

High-Pressure Drains.—All drainage points in the high-pressure steam mains and steam separators were connected to the Holly gravity return system, designed by Westinghouse, Church, Kerr, and Company, and shown typically on Fig. 12, which has at its low point a receiver, down into which the drain pipes lead. At an elevation of about 30 ft. above the boiler water line there was placed a discharge chamber with which the receiver below was connected by a riser pipe.

A direct return line from the discharge chamber restored the water of condensation to the water space in the boilers at substantially the boiler temperature. Pressure in the discharge chamber was sustained by way of the riser pipe, the upward movement of steam raising the water of condensation by entrainment, and with a pressure loss of few pounds.

HOLLY GRAVITY RETURN SYSTEM
TYPICAL ARRANGEMENT AND STARTING DIRECTIONS



DIRECTIONS FOR STARTING HOLLY SYSTEM

Open return valves, *A-A*, at boilers under steam. Open regulating valve, *B*, slightly. Open valve, *E*, in raiser line. Open all valves in drip lines to receiver. Open starting valve, *C*, until steam blows through, then close. The system is then in operation. When plant is not under steam, open valves, *C*. and *D*

Drip Lines, No. 1, 2, 3, and 4
Riser Line, No. 5
Return Line, No. 6
Vent Line, No. 7

FIG. 12.

The discharge chamber was vented for the purpose of clearing the system of accumulating air and rendering the riser action more active, the small amount of vapor escaping being discharged into the feed-water heater.

The whole system operated continuously, without dependence on mechanically-operating elements subject to failure, other than its component piping.

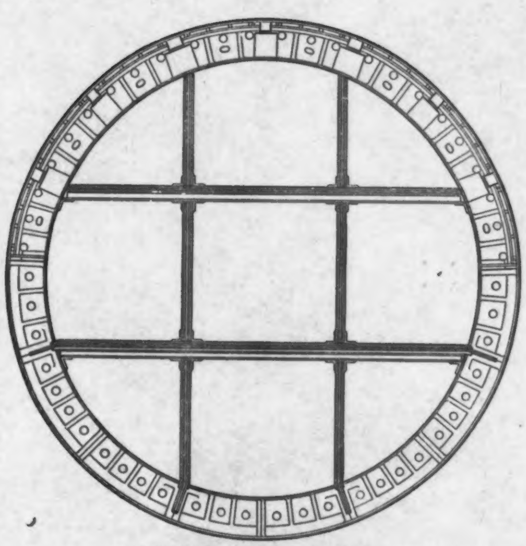
Low-pressure drains were dealt with by steam traps discharging to the hot well.

Air Distribution.—The intakes on the Long Island side consisted of an independent 18-in. vertical galvanized pipe for each of the cylinders. Each pipe rose above the power-house roof, and was crowned with a conical top above a wire screen.

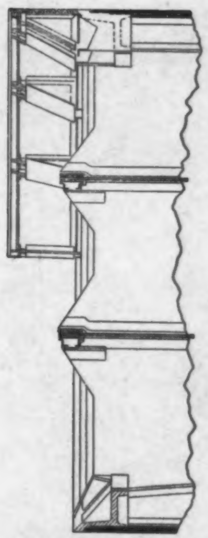
On the Manhattan plant, a large galvanized-iron duct was built into the foundations under the compressors, with inlets to each cylinder, and a vertical intake, 2 ft. 6 in. by 1 ft. 6 in., at the west end of the power-house, and a 4 ft. 6 in. by 2-ft. intake at the southeast corner rose above the roof, and turned over with a slight downward bend to prevent rain from entering; the opening was screened with wire netting.

The discharge lines consisted of two easy 12-in. bends from each cylinder to the after-cooler, with a 12-in. connection, between the after-coolers and air receivers, which entered the receiver at the top and left it about one-third of the way up, so that the air flowing down through the height of the receiver deposited some of the moisture and oil which the after-cooler had failed to abstract.

The outlets from the air receivers were 10 in. in diameter, and led to a four-way manifold with a 10-in. sluice-valve on each branch, connecting with a tee to the four 10-in. air lines, one for each tunnel. This made it possible for each compressor to discharge into any or all of the four tunnels, and each tunnel to have any or all of the compressors discharge into it. Four 10-in. air lines, each with two tees and three valves for a by-pass, as specified, led from the power-house into the yard, two going down each shaft. They were cross-connected at the bottom of the shaft, with a sluice-valve between, and one 10-in. main entered each tunnel where it branched off into two 8-in. lines with an 8-in. sluice-valve outside each air-tight bulkhead. Inside the bulkhead, another 8-in. valve was fitted, and beyond it a non-return

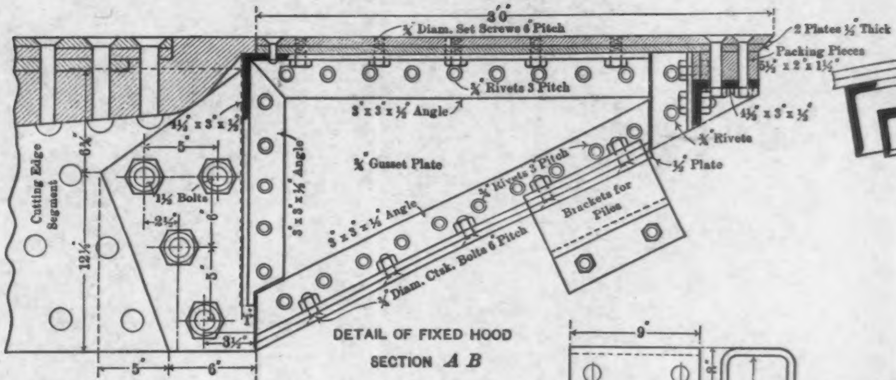


FRONT ELEVATION OF SHIELD
SHOWING FIXED HOOD

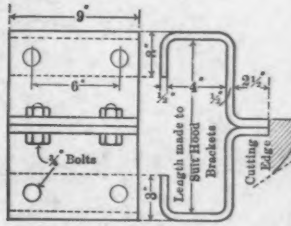


SECTIONAL ELEVATION OF SHIELD
SHOWING HOOD IN POSITION

FIXED HOOD

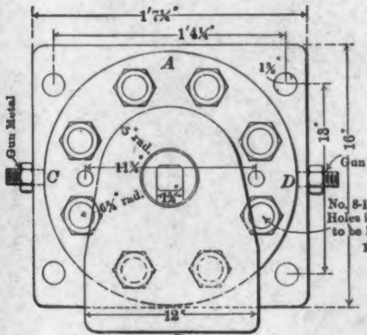


DETAIL OF FIXED HOOD
SECTION *A B*

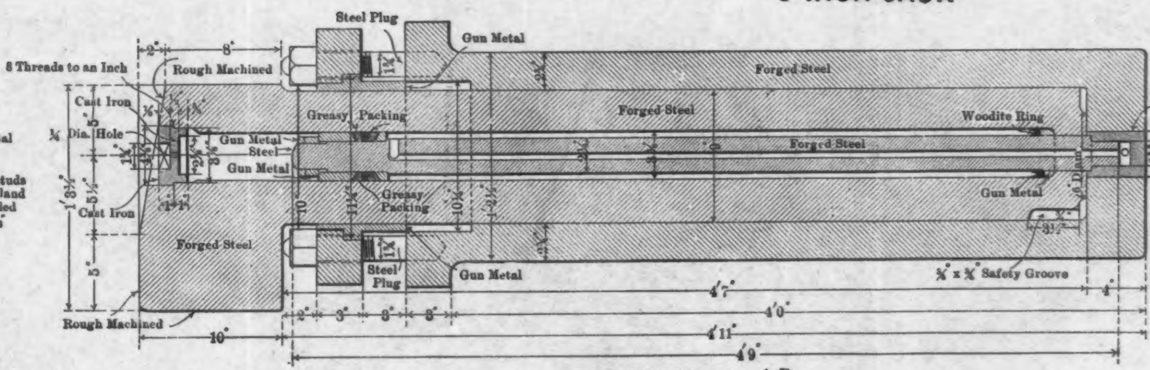


DETAILS OF BRACKET
FOR PILES

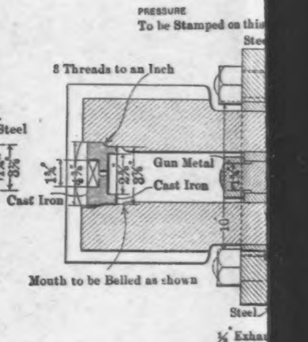
9-INCH JACK



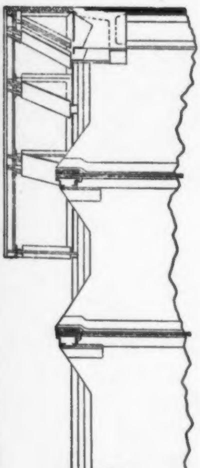
FRONT ELEVATION



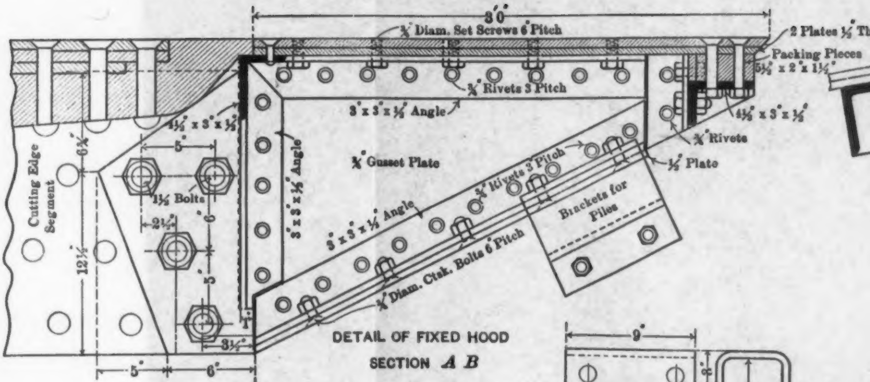
SECTION THROUGH *A B*



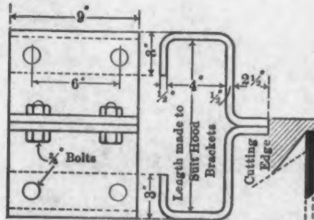
FIXED HOOD



SECTIONAL ELEVATION OF SHIELD SHOWING HOOD IN POSITION

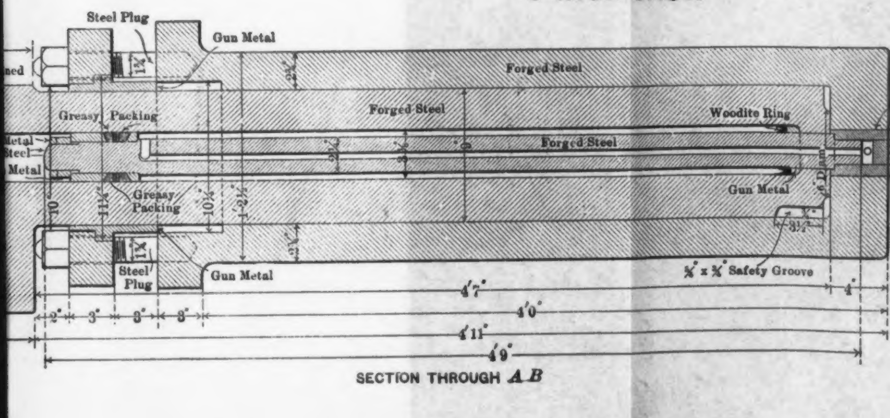


DETAIL OF FIXED HOOD
SECTION *A B*



DETAILS OF BRACKET FOR PILES

9-INCH JACK



SECTION THROUGH *A B*

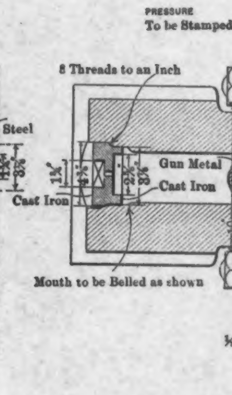


PLATE V.
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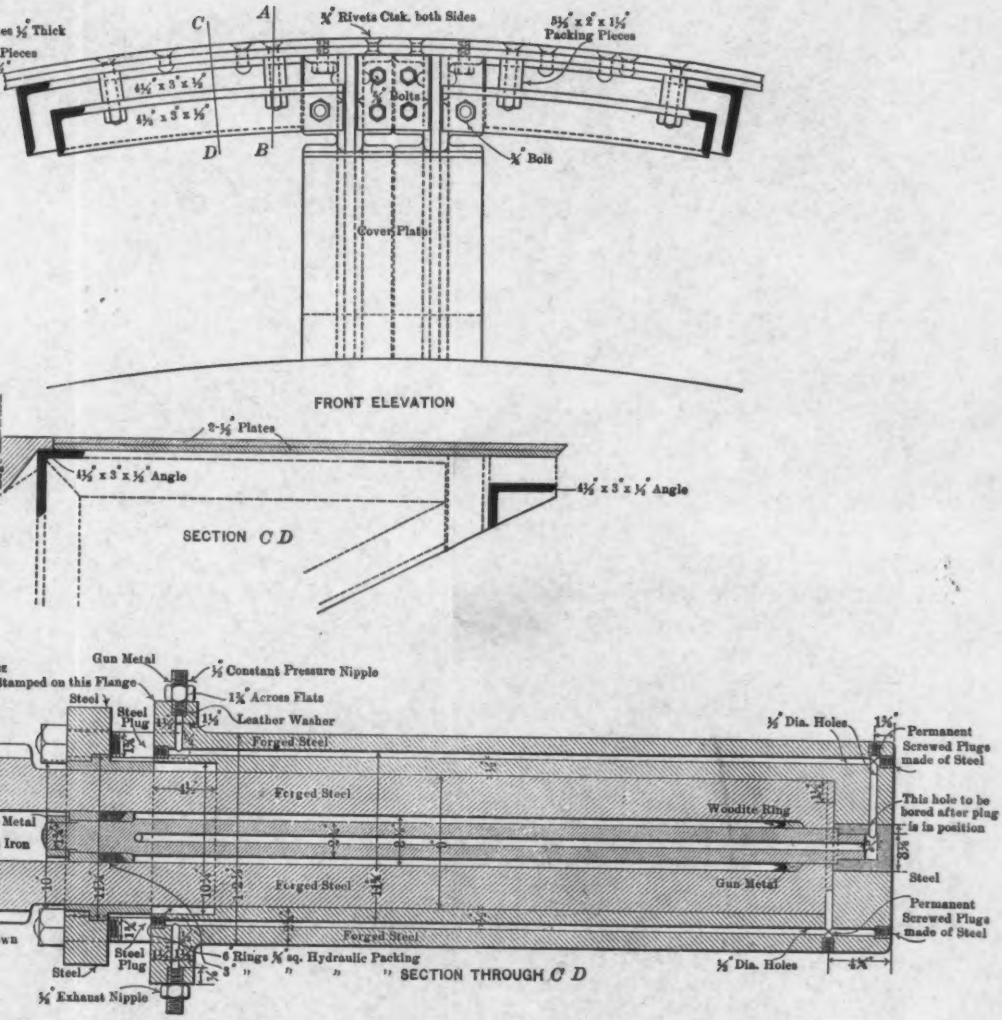
JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.



FRONT ELEVATION

SECTION *C D*

SECTION THROUGH *C D*

valve. Between bulkheads, 8-in. tees with valves were provided from each main for controlling the pressure.

At the delivery end of the 8-in. mains, which were carried up as near the face as possible, light non-return flap-valves were fixed. At the beginning of the work the original specifications were carried out, whereby the air from the mains was connected to the shield by a large flexible rubber pipe, so that the air was blown right into the shield.

It was ultimately found that this was unnecessary, because the same result could be achieved by carrying a blow-out line into the shield, and was much more effectively dealt with than either of these methods by leakage at the face. The 10-in. air mains were standard lap-welded pipe, with extra heavy flanges. The bends and tees were of cast-iron. The 8-in. lines were lap-welded, light-section pipes, with loose flanges and Vanstone joints, made by Stewart and Lloyd, of Glasgow, about $8\frac{3}{16}$ in. inside diameter and $\frac{3}{16}$ in. thick. They were very convenient for handling in the compressed air, as they were very much lighter than the standard lap-welded pipe.

On the Manhattan side, on account of trouble which was experienced through one of the 10-in. lines in the shaft splitting a flange, additional tees were placed at the top of the shafts in the two 10-in. lines, and 8-in. lines were led from these tees to the opposite tunnel to that which the 10-in. line entered, and sluice-valves were placed at the back of each tee. This gave an additional air supply in the event of the vertical pipe being damaged by materials being lowered to the tunnel.

For controlling the pressure in the tunnels, a $\frac{1}{2}$-in. pipe with an ordinary pressure gauge was led from each tunnel to the power-house, and a branch with a recording gauge was led to the office. The gauges in the power-house were fixed on a gauge-board along with recording pressure gauges from each air line, and one mercury gauge on a manifold as a check. The engineer was given the required pressures for each tunnel, and, when it was advisable to regulate the pressure according to the tide, a schedule showing the hourly pressure was used, and a Silvertown electrical tide gauge, controlled by a float in the river, was fixed on the gauge-board in the power-house, and in the office. A supplementary cardboard dial was placed on the tide gauge to show the minimum safe pressure at any tide level; that is, the lowest hydrostatic head to the top of the tunnel.

The power-house engineer was able to control the tunnel pressure

very steadily by the return gauges. Occasionally, confusion would result from the ½-in. pipes being injured and leaking, thus showing a lower pressure in the power-house than was recorded in the tunnel; but, in that event, the telephone system was so complete that the engineer could keep in touch with the walking boss. Telephones to every heading were connected with the main switch-boards in the offices, which had connections to each power-house, and it was possible to communicate with the men in the heading from any point, in connection with the city telephones.

At times as much as 20 000 cu. ft. of free air per minute was forced into one tunnel at a pressure of 35 lb. per sq. in., or an actual volume of 6 000 cu. ft. of compressed air at a velocity of more than 8 500 ft. per min. through two 8-in. pipes. Such a speed involved great friction loss, amounting to as much as from 10 to 15 lb., depending on the length of tunnel constructed. During "blows" requiring such quantities of air, the power-house engineers forced their machinery to the utmost in their endeavor to hold the pressure in the tunnel to the schedule. On these occasions they were surprised to receive orders to reduce the power-house pressure gradually, and more surprised still to find that the tunnel pressure did not fall when the compressors slowed down.

It appeared from this that, after a certain leakage took place, the more air pumped into a blowing tunnel, the more the tunnel would take without improving the pressure. This will appear to be quite logical, within certain limits, after a little thought.

Distribution of High-Pressure Air.—High-pressure air for rock drills, winches, caulking hammers, grout pans, etc., was delivered from the high-pressure air receiver by a 6-in. main which led down each shaft. A 4-in. main led from the 6-in. pipe along each tunnel, and T-connections were put in at suitable intervals along the tunnel, for caulking, grouting, etc. No reheating was attempted. The pipes were standard, lap-welded, with flange connections.

Hydraulic Pressure.—Hydraulic pressure for shoving the shields was supplied at 6 000 lb. per sq. in., and, for the erectors, a pressure of 1 000 lb. per sq. in. was used. The engines adopted for developing this pressure were of the cross-compound, steam, differential, water type, built by the Tannett Walker Company, with 14 and 24-in. steam cylinders, and 18-in. stroke, 2 and 1$\frac{13}{32}$-in. differential rams, and 18-in. stroke.

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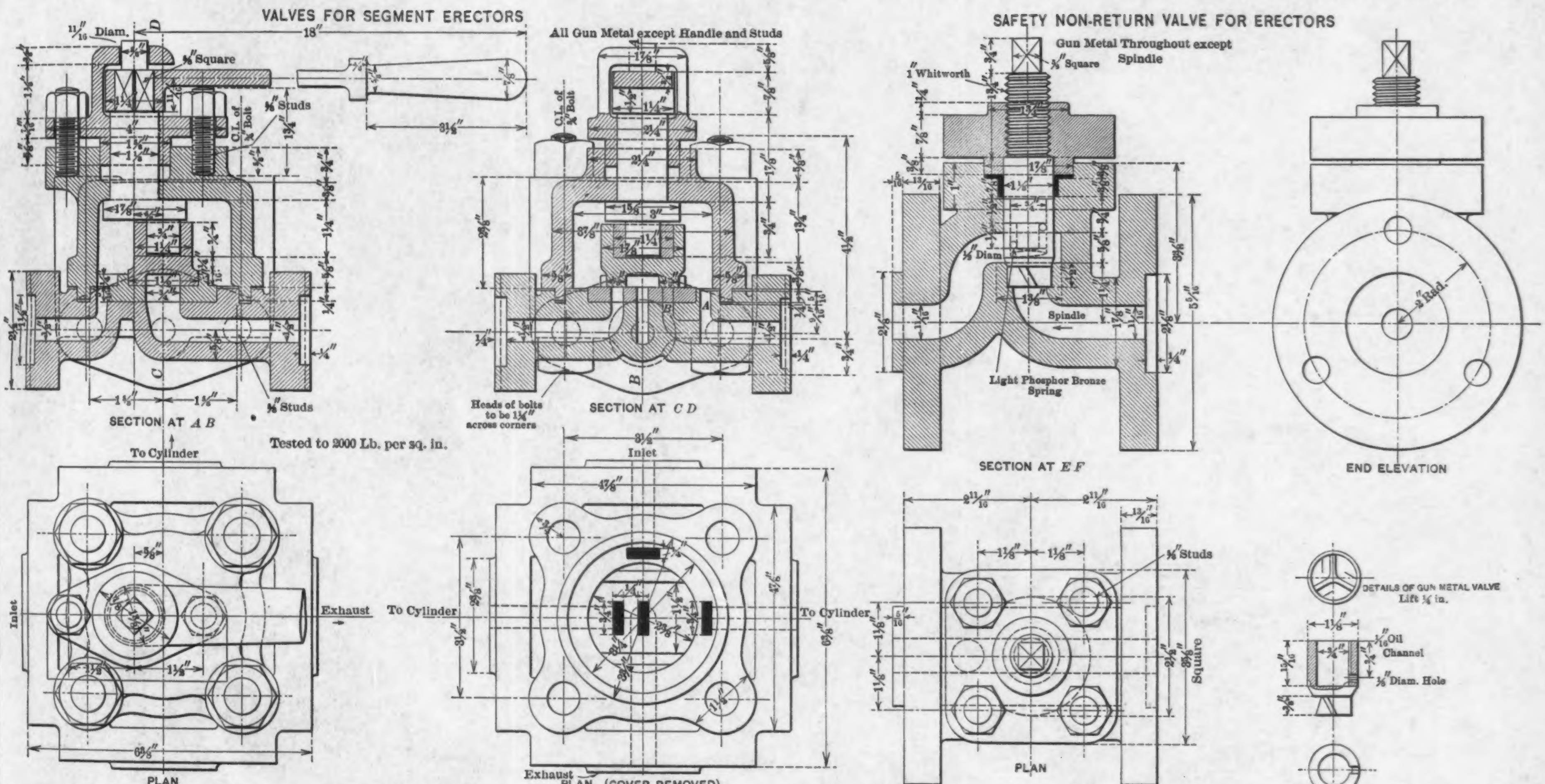

These pumps had a capacity of 6 786 cu. in. at 6 000 lb. per sq. in. developing 60 h.p. at 30 rev. per min., and 18 000 cu. in. at 1 000 lb. pressure, making 80 rev. per min. and developing 18 h.p. Each steam piston had two piston rods on the horizontal center line, which passed on either side of the 2-in. hydraulic plunger and its casing, and were bolted to a heavy cross-head on which were bolted the rams, and a fork connecting rod, bearing on extended cross-head gudgeon pins, passed over the casing of the $1\frac{13}{32}$-in. ram to the cranks on either side of the fly-wheel. The plungers were outside-packed, and, owing to the differential action, they required the same effort on each stroke and only required one suction valve and one discharge valve for each pair of differential rams, the 2-in. ram being just twice the area of the $1\frac{13}{32}$-in. ram.

The number of engines and the capacity were computed on the assumption that the full $2\frac{1}{2}$-ft. stroke of 27 jacks, 9 in. in diameter, on four shields, with 10% leakage, would be required in $\frac{1}{2}$ hour, and amounted to 7 600 cu. in. of water per minute.

For low-pressure water, the complete movements of the erectors for placing a ring of iron were calculated. The erector, having an $11\frac{1}{2}$-in. piston on an $8\frac{1}{8}$-in. ram with a $3\frac{1}{2}$-ft. stroke, and the push and pull for placing the plates having a $4\frac{1}{4}$-in. piston on a 3-in. ram with a stroke of 6 ft. 2 in., the complete movements for two erectors on one shield, with 10% added for leakage, assuming that the whole ring could be placed in $\frac{1}{2}$ hour, amounted to 2 020 cu. in. of water, and, with the four shields, 8 064 cu. in.

It was decided, therefore, to purchase three Tannett Walker engines, as described above, two of them being used for high pressure, giving a capacity of 13 572 cu. in. displacement as against a requirement of 7 600, and one being used for low pressure with a capacity of 18 000 cu. in. as against 8 084 required, so that practically double the calculated capacity was installed.

The high-pressure hydraulic system consisted of a $1\frac{1}{8}$-in. inside diameter and $1\frac{15}{16}$-in. outside diameter, extra heavy, American, hydraulic pipe, built up of three different thicknesses of pipe shrunk one on the other, joined by heavy cast-iron couplings. It was tested in the yard to 6 500 lb. per sq. in. before being sent to the tunnel.

From each of the three engines on each side of the river a $1\frac{1}{8}$-in. pipe, having a screw-down stop-valve, was joined to a manifold with

four branches. Each branch had a screw-down valve, and led to one of four main high-pressure lines leading to the shafts; two of the pipes led down each shaft and were joined at the bottom, forming a loop.

From each end of the loop a 1⅛-in. line entered each of the two tunnels at the foot of the shaft, and on either side of the connections a screw-down valve was fixed in the loop as well as on the line entering the tunnel. By this means it was possible, if one of the lines to the shaft burst, to use the other.

The pressure line along the tunnel was connected to the valve box in the shield by a flexible high-pressure armored-hose pipe. These frequently gave out, and, as often as not, the connection was made with a piece of copper pipe of sufficient length to allow the shield to move forward without breaking the joint. On each main was fitted a safety valve, so that if the pressure at the shield was shut off suddenly the stored energy of the fly-wheel would not burst the pipes. A by-pass near the shield was opened before the pressure was shut off the jacks.

The low-pressure hydraulic system consisted of two lines of pipe 1⅛ in. in diameter inside and 1¾ in. outside, with male and female joints, and leather gaskets held by 5½-in. flanges with three bolts ⅝ in. in diameter.

All three engines were coupled, through a stop-valve, to a loop formed by joining the two low-pressure mains, and a valve at each end of the loop cut off either of the two lines.

From each line connections controlled by stop-valves led to the accumulator and down each shaft, where a loop was formed, as on the high-pressure line, from which the low-pressure mains led into each tunnel. The accumulator supplied the erectors with a constant pressure, so that, if the engine speeded up or stopped suddenly, the erector would not lash about and injure the workmen.

As the total quantity of water required for the building of one ring in four tunnels simultaneously was 60 634 cu. in., including 10% loss, it was decided that the accumulator ought to supply one-third of this capacity. This gives the engine considerable latitude. The accumulator, therefore, was made with a capacity of 20 358 cu. in., or 12 in. in diameter and 15 ft. stroke. One was ordered for each side of the river from R. D. Wood and Company, of Philadelphia.

The accumulators were designed with the plunger fixed to the base

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FIG. 1.—GROUT PAN.

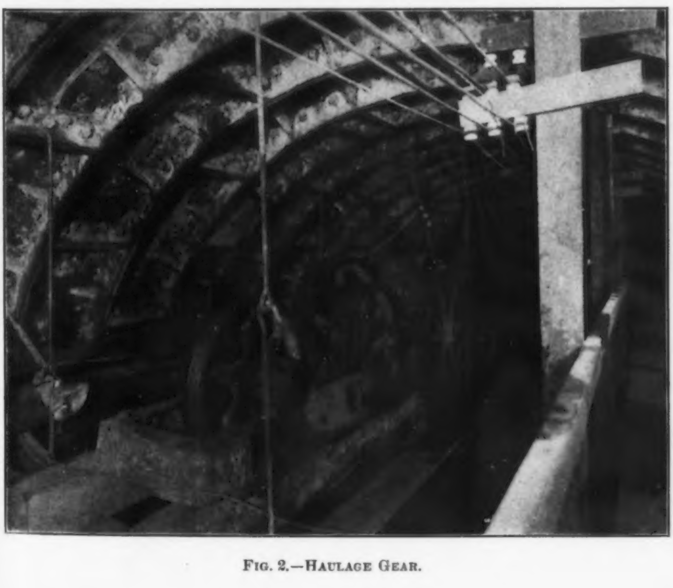


FIG. 2.—HAULAGE GEAR.

and standing upright. The cylinder which surrounds the plunger was tested to a water pressure of 3 000 lb. per sq. in. before erection. Around it was built a steel tank of sufficient size to load the accumulator to 1 000 lb. per sq. in. when filled with material weighing not less than 100 lb. per cu. ft.

Castings bolted to the side of this circular ballast tank slid on vertical timber guides, and the whole plant was housed in a steam-heated building. It was connected to the steam stop-valve of the low-pressure hydraulic engine by a light wire rope, so that, when it fell, the stop-valve opened and then closed when the accumulator rose near the top of the stroke, and, if it continued rising, a rigid steel rod attached to a relief valve was lifted to prevent over-stroking.

It was found necessary for a time at Manhattan to supplement the three pumps with an electrically-driven Watson Stillman pressure pump. This was made strong enough for 6 000 lb. per sq. in., but was used almost exclusively at a pressure of 1 000 lb., coupled with the accumulator. It was fitted with four rams, $1\frac{1}{4}$ in. in diameter and having a stroke of 6 in., and driven through gearing by a 50-h.p. Westinghouse motor, built for 250 volts.

On the Long Island side, for the same reason, it became necessary to supplement the low pressure by means of one belt-driven gear, three-throw, 6-gal. per min., Berry pump, with rams 2 in. in diameter and 6 in. stroke, driven by a 30-h.p. motor.

For a time, this pump and another of the same type, but two-throw, were used at East Avenue for one of the shields, and later a Watson Stillman air-driven, duplex, 5 500 lb. pump, with two air cylinders, 14 in. in diameter, and differential duplex water cylinders $1\frac{1}{2}$ and $2\frac{1}{8}$ in. in diameter and 12 in. stroke, was used for one of the East Avenue shields. It was found convenient to mount this on the traveling staging at the back of the shield. This saved long lengths of hydraulic pressure pipes through the tunnels.

Fire Service.—Fire service was provided at each site, with a 4-in. main in the yard and $2\frac{1}{2}$-in. stand-pipes; 50-ft. lengths of hose pipes, with standard connections and nozzles, were fixed on each pipe and folded up in a box. Water was supplied to this system by special meter, and connection was also made to a high-pressure service pump in the power-house, with a salt-water suction. The main also entered the men's rooms and offices. In the tunnels, the same fire service was

available, with connections every 200 ft., and at the shield and bulkheads, where there was the most likelihood of fire, there was, in addition, a connection on both hydraulic services. In each air-lock a fire connection was fixed, with a short length of hose ready for use, and, in addition, a high-pressure air connection was led to each air-lock. The air connection was adopted after a serious fire had occurred in one of the tunnels on an off Sunday through the carelessness of the tunnel watchman who was killed by fire and smoke, evidently while asleep on duty. The men attempting to get to work on Monday morning were suffocated by the hot and smoke-charged air entering the lock from the tunnel. A high-pressure hose pipe was connected to the decompression cock and the air-lock was filled with fresh high-pressure air, so that the men were able to get inside the tunnel to put out the fire.

The high-pressure air combined with the fire-hose made it possible to control a fire near the bulkhead. In addition to these precautions, each bulkhead was fitted with a 6-in. pipe mounted with three double-standard Siamese fire connections, with non-return valves, on the outside or atmospheric side of the bulkhead, and, on the pressure side of the bulkhead, there were four standard fire connections, so that in the event of an uncontrollable fire, the fire brigade could couple high-pressure hose pipes and flood the tunnel.

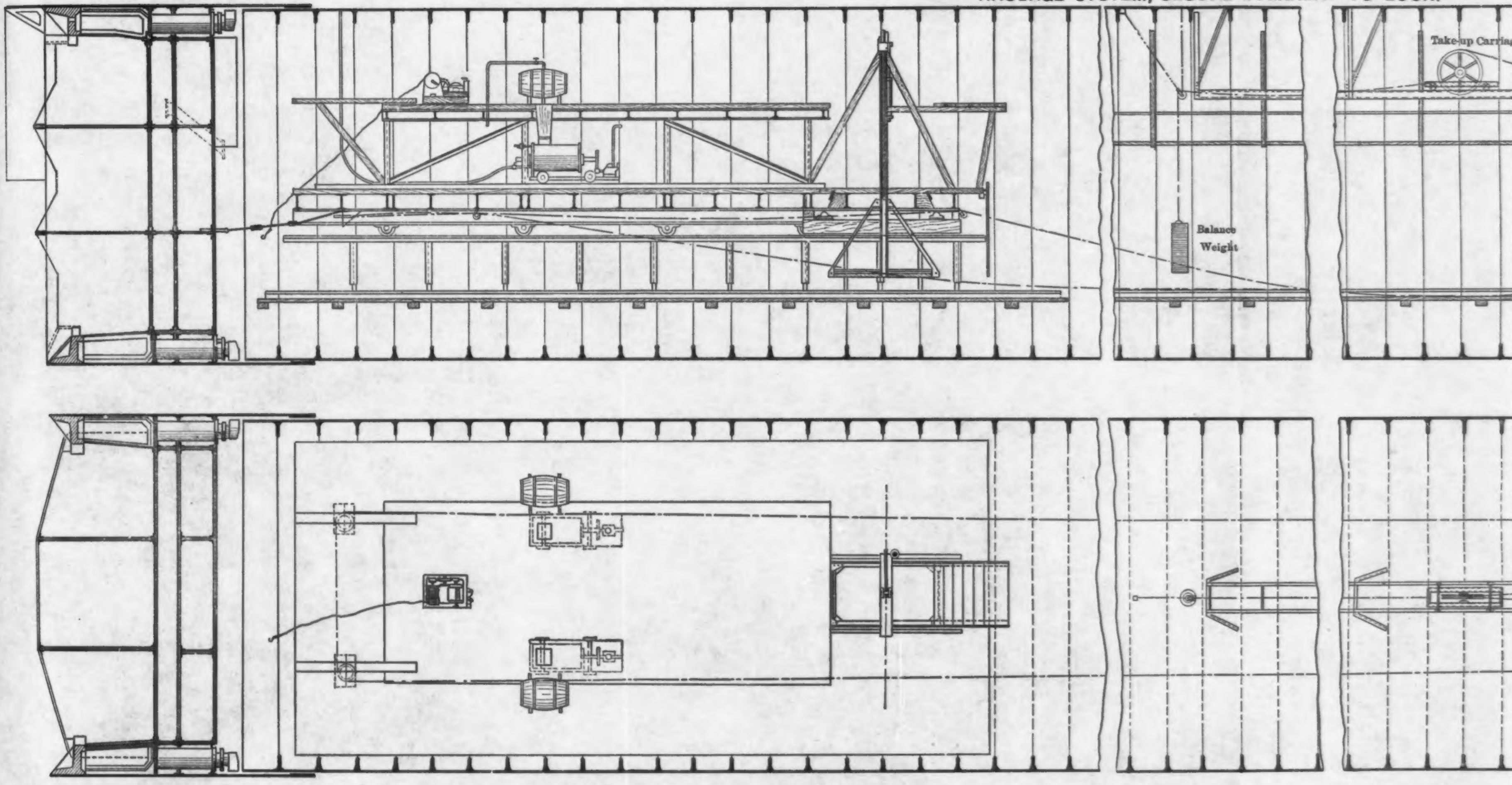
After one of the powder magazines, with about 800 lb. of 60% dynamite, had burned up, without any known reason, while the powder watchman was beside it, it was decided to fix in the roof of each powder magazine a 4-in. connection with a valve controlling it at a safe distance away, so that if a fire started in the magazine or anywhere near it, the valve could be opened and the powder magazine kept practically full of water.

In connection with the powder magazines, which come under the Fire Department, the detonators were always kept some distance from the magazines, which were of the standard approved type adopted in New York City.

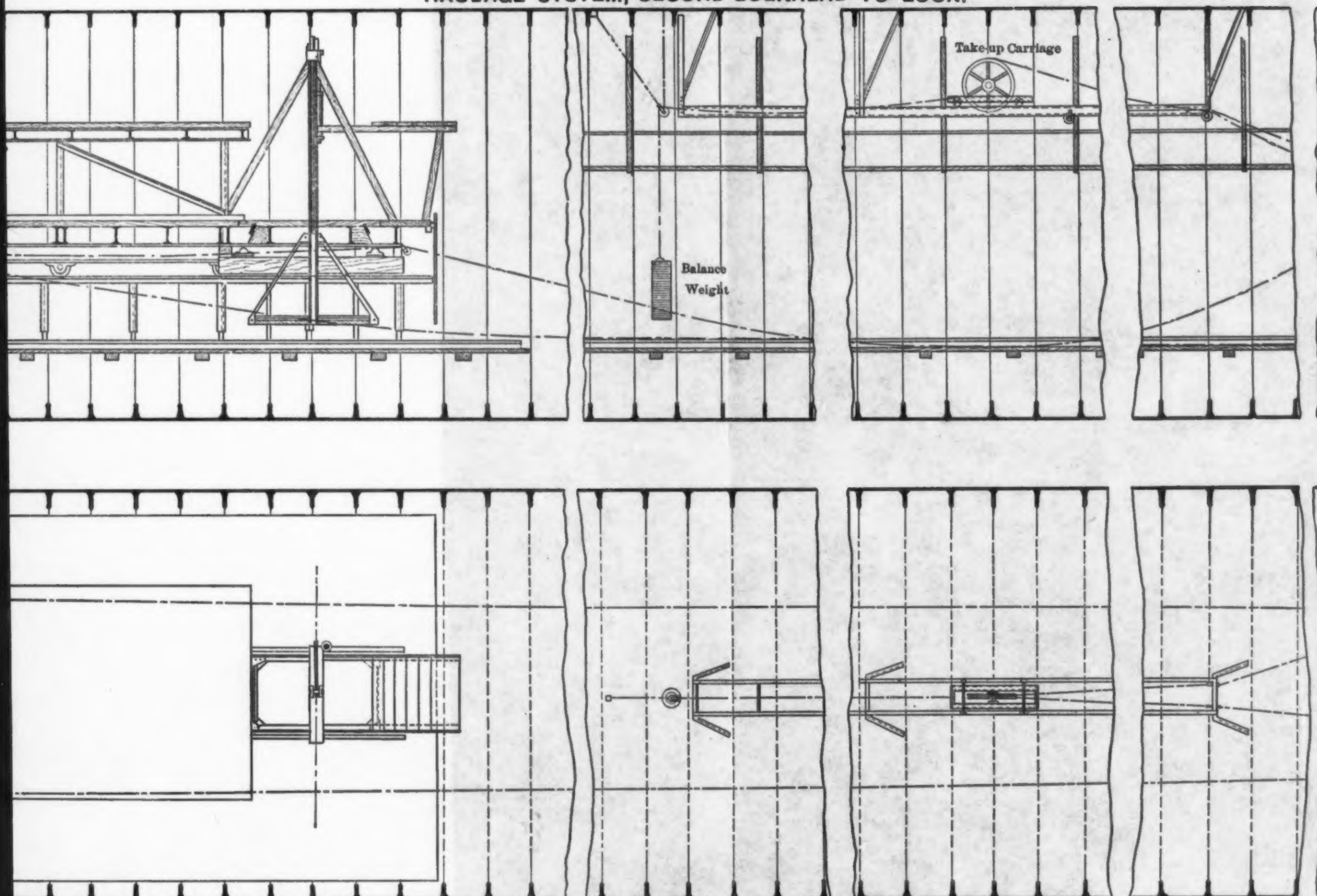
For the fire protection of oil stores, the roof of each oil store had a very thin matchboard lining, about 8 in. below the roof, and the space between was filled with sand, so that if the oil caught fire, the ceiling would very quickly burn through and dump the dry sand on top of the oil.

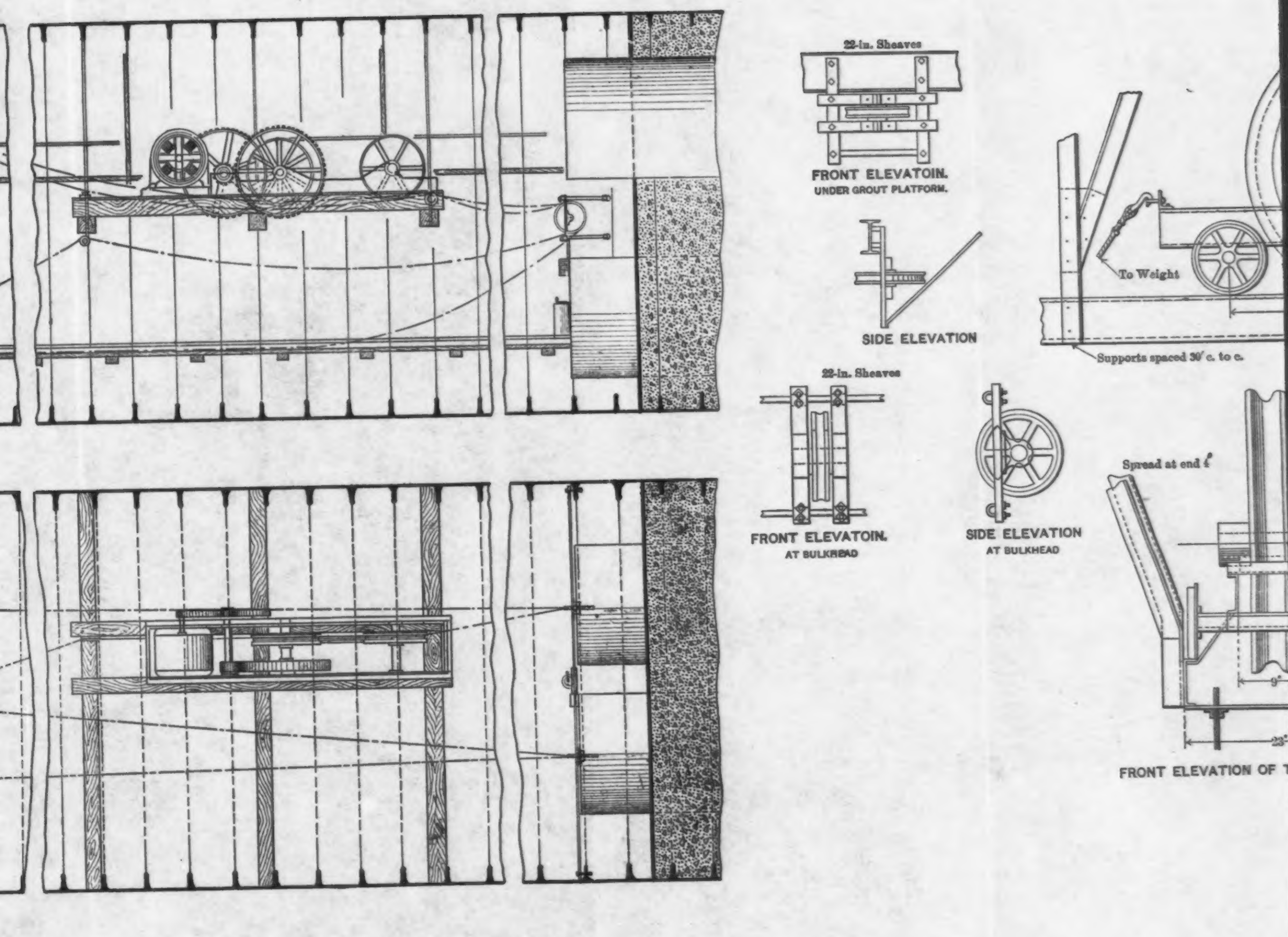
On the Manhattan side, where repeated attempts were made by

HAULAGE SYSTEM, SECOND BULKHEAD TO LOCK.



HAULAGE SYSTEM, SECOND BULKHEAD TO LOCK.




22-in. Sheaves
FRONT ELEVATOIN.
UNDER GROUT PLATFORM.
SIDE ELEVATION
22-in. Sheaves
FRONT ELEVATOIN.
AT BULKHEAD
SIDE ELEVATION
AT BULKHEAD
To Weight
Supports spaced 30' c. to c.
Spread at end 6"
9"
23"
FRONT ELEVATION OF T

BULKHEAD TO LOCK.

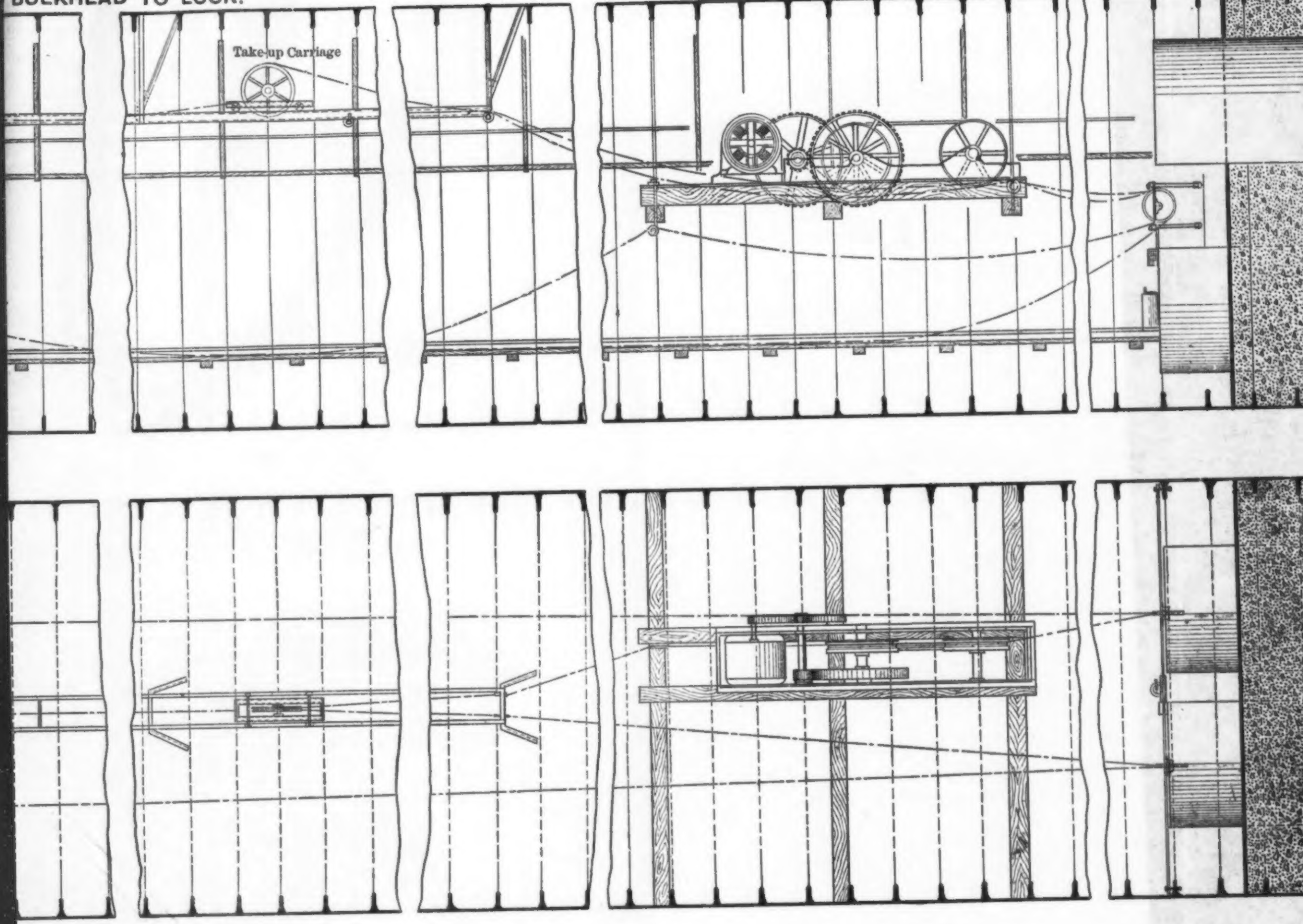


PLATE VIII.
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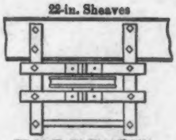
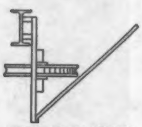
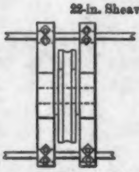


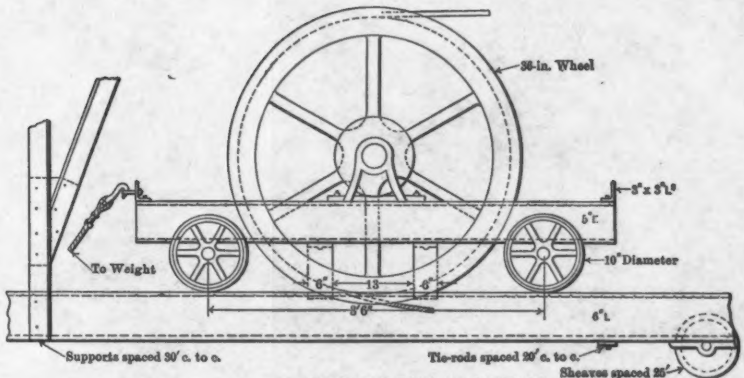
FRONT ELEVATOIN.
UNDER GROUT PLATFORM.


SIDE ELEVATION

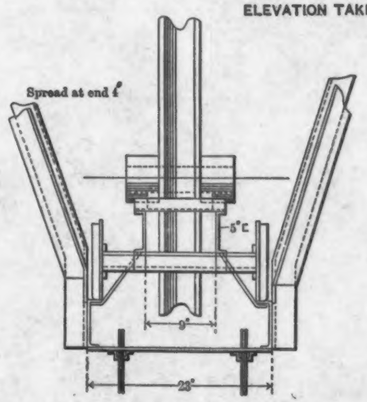


FRONT ELEVATOIN.
AT BULKHEAD


SIDE ELEVATION
AT BULKHEAD



ELEVATION TAKE UP-CARRIAGE



FRONT ELEVATION OF TAKE-UP CARRIAGE.

incendiaries to burn down the office buildings and the men's rooms, two 3-in. perforated pipe lines were run above the ceiling of each building, as a precaution, so that in the event of a fire the building could be drenched. The usual chemical fire extinguishers prescribed by the underwriters were placed in all buildings.

Electrical Apparatus.—In determining the amount of electrical energy necessary, calculation was made of the horse power required for the various machines, which were to be driven by electricity.

The original estimate for each site covered:

Two hoists at 30 h.p.	60 h.p.
Four haulage gears at 30 h.p.	120 "
Electric light for offices and tunnels	85 "
Stone crusher	40 "
Concrete mixer	30 "
Pug mill	15 "
Work shop	30 "
Total	380 h.p.

Estimating the mechanical efficiency of the engine and dynamo at 90%, and the efficiency of the motors at 90%, gave a combined efficiency of 81%, or a total horse power of 470 for each working site; but, as all this plant could not be in operation at the same moment, it was decided to consider that not more than 50% would be demanded at one time, making the requirements 235 h.p. for each site, or 179 kw.

For the Manhattan side, three units of 75 kw. each, and for the Long Island side, which also had to take care of the East Avenue site, three units of 160 kw. were purchased.

On account of the limited ground space available, vertical engines were decided on, and those purchased were the Reeves cross-compound vertical engines, direct-connected to General Electric generators. The larger units had engines of 12½ and 20 in. in diameter with 16-in. stroke, developing 225 i.h.p. at 230 rev. per min., and the Standard General Electric dynamo of 160 kw., 640 amperes, 250 volts, at 230 rev. per min.; the smaller units were 8½ and 17 in. in diameter with 12-in. stroke, at 270 rev. per min.

The speed of the engines was guaranteed to vary not more than 1½%

when working under extreme changes of load, within the rated capacity up to 150% overload.

The steam consumption was guaranteed not to exceed 19 lb. per i.h.p. per hour for the large engines, and 20 lb. for the smaller engines when operating with an initial steam pressure of 125 lb. per sq. in. and a 26-in. vacuum, developing normal horse power, and at one-half load not to exceed 20½ lb. for the larger engines, and 21½ lb. for the smaller engines. A test was carried out which showed that these conditions were fulfilled. The engines ran very smoothly, and took care of great changes of load with remarkable ease, the speed being regulated to such a degree that three engines could work together in parallel.

The generators were equal to all demands. It was guaranteed that after 24 hours' run at the rated capacity they would have a temperature rise of not more than 35° cent., on the armature, field-coils, and commutator, above that of the air surrounding the machine.

With 150% of full load for 2 hours, the temperature rise of any part of the machine was not to exceed 55° cent. The machines were guaranteed to carry 50% overload for 2 hours without injurious sparking, and 100% overload momentarily without flashing over or injurious sparking. The efficiency was guaranteed to be 91% at full load, and slightly less above and below this. In the larger machines, ½% better efficiency was guaranteed.

In order to measure the current passing to the different parts of the works, the mains were metered at the switch-board. When it was found that the boiler capacity was insufficient for the demand made upon it by the tunnels, a supplementary supply of electricity was contracted for with the Edison Company at Manhattan, and with the Pennsylvania Railroad Company at Long Island City. The Edison supply, being direct current of the same voltage, was coupled up direct to the switch-board, but that at Long Island, being 11 000-volt, 3-phase, alternating, it was necessary to install rotary converters. Two standard Westinghouse 300-kw. converters were selected, wound for direct current at 250 volts, and fitted with 8 poles suitable for a frequency of 3 000 alternations per min., or 25 cycles per sec., at the normal speed of 375 rev. per min. The collector rings were connected for 3-phase current at approximately 153 volts. The rotary converters were started up by an alternating-current motor on the shaft.

The normal full-load rating of the machines was a direct current

of 1 200 amperes at 250 volts. The power factor of the alternating current being 100%, the machines had an efficiency of 90% at one-quarter load up to 94% at full load, and could stand 50% overload for 1 hour with no serious sparking.

The 11 000-volt alternating current, before going to the rotary converters, was transformed to 155 volts low-tension by three oil-insulated self-cooling transformers of 225 kw. each. The combined efficiency was 91.5% at full load; this included the rotary converters and the transformers. When these converters were installed at Long Island City, one of the 160-kw. steam-generating sets was taken over to Manhattan.

The distribution of the electric power consisted of two sets of underground, three-conductor cables from the Pennsylvania Railroad power-house at Long Island City to the Contractors' power-house, for carrying 11 000-volt, 3-phase, alternating current. Here the current was distributed to two sets of step-down transformers, one at 400 volts, for two 600-h.p. motors, driving the air compressors, and the other at 155 volts for the two 300-kw. rotary converters feeding motors and lights at 250 volts, direct current.

Two 160-kw., 250-volt, steam-driven generators were operated in parallel with the converters.

A transmission line, 2 000 ft. long, was run to the East Avenue shaft, with a capacity of 115 kw. at 90% efficiency, consisting of two pairs of 500 000-cir. mils for power and two pairs of No. 000 B. & S. for lights. The electric-light mains in the tunnels at each site were of No. 1 B. & S. At the Manhattan side, the electric power was obtained from the steam-driven generators, three of 75 kw. and one of 160 kw. at 250 volts, with a stand-by connection from the Edison Company at 250 volts.

Shields.—There were two types of shields, namely, the heavy under-river type, Plate III (also shown by Plate LXV and Fig. 1, Plate LXVI, of the paper by Messrs. Brace, Mason, and Woodard*), and the lighter type, Fig. 13, for the land section driven from the East Avenue shaft under the Long Island Railroad depot. The under-river type was designed by E. W. Moir, M. Am. Soc. C. E., Vice-President of the Contractors' firm, and was very like the Blackwall tunnel shield, also designed by him. The principal point of difference between these shields and others used around New York is their massiveness. The

* *Transactions*, Am. Soc. C. E., Vol. LXVIII.

cutting edges, as can be seen from Plate III and Fig. 13, are very heavy, and yet, for the work before them, they proved none too heavy, as one of the cutting edges was turned up by being pushed on an almost imperceptible incline of rock, and had to be repaired under air pressure. The total weight of one of these shields, without jacks or erectors or any accessories, was 185 net tons.

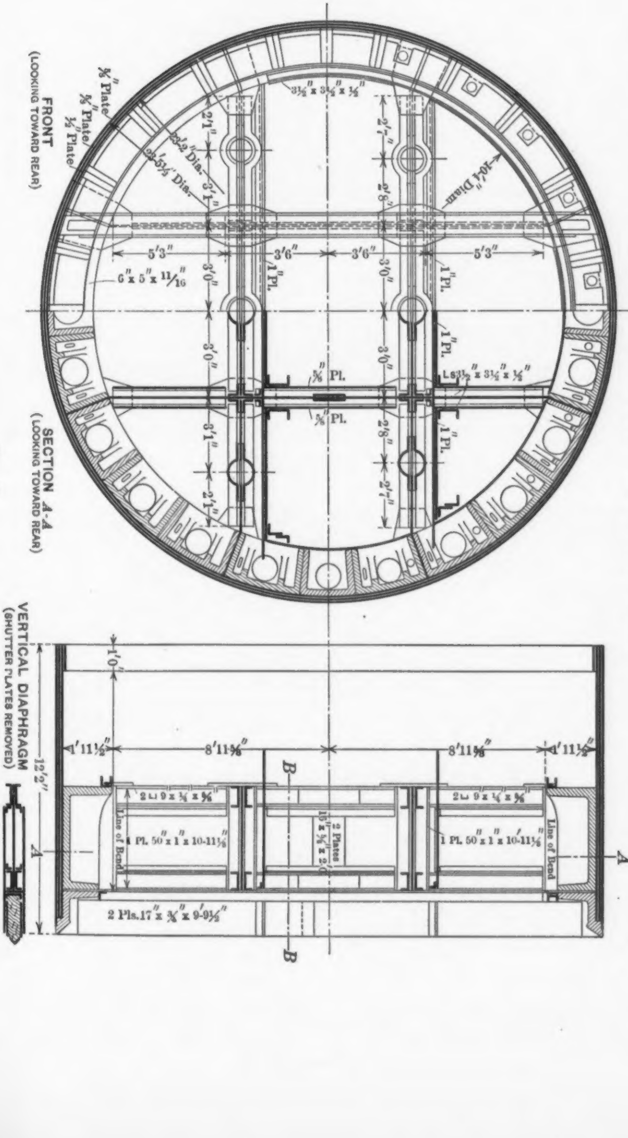
Eight subaqueous shields were ordered from the New York Shipbuilding Company's yard at Camden. They were 23 ft. 6½ in. in outside diameter and 18 ft. long around the edge, with the horizontal floors projecting 9 in. in advance of the cutting edge between the vertical diaphragms, and running back to the line of the cutting edge on each side.

The shields were divided into nine pockets by two vertical diaphragms and two horizontal floors. The horizontal floors were made up of two plates, ⅝ in. thick, and were non-continuous for a width of 6 ft. 10 in., butting against the vertical diaphragms which were continuous for a width of 6 ft. 10 in.

To give each floor the necessary beam strength, two continuous doubling-plates, ¾ in. thick and 12 in. wide, and an additional stiffener underneath, made of two 1-in. plates, channel, and Z-bar, passed around the front of the vertical diaphragms to form the compression chord of the beam, and, at the same time, a cutting edge for the horizontal floors. Continuous doubling-plates and angles, that is, two ⅝-in. plates, 18 in. wide, and four 4 by 4 by ⅝-in. angles for each floor, passed around the back of the vertical diaphragm to form the tension chord of the beam. The vertical diaphragms consisted of two ⅝-in. plates with a 1¼-in. space between. Distance pieces or strips, 1¼ in. thick, at a pitch both horizontal and vertical not exceeding 18 in., were riveted between the two ⅝-in. plates to unite them and give proper stability under compression.

To give each vertical diaphragm the necessary beam strength, one plate, 1¼ in. thick and 19 in. wide, and two plates ¾ in. thick and 12 in. wide, were riveted in the front to form the compression chord, the tension chord being formed of one plate, 1¼ in. thick and 12 in. wide, two plates, ¾ in. thick and 12 in. wide, and two 4 by 4 by ⅝-in. angles riveted up the back.

There were three skin plates of ¾-in. steel, the outer and middle plates being 17 ft. 6 in. long. The inner plate was 17 ft. 3 in. long. The



23-FOOT LIGHT-TYPE SHIELD

Fig. 18.

skin plates were divided up around the circumference in such a way that the shield could be built for transportation in eight sections, including the hydraulic-jack boxes. The middle and inner skin plates lapped the outer plates by 12 in. and 24 in., respectively.

From the back of the cutting edge, for the full extent of the jack boxes and the stiffening circumferential angle ring, a fourth $\frac{3}{4}$-in. plate was riveted to the skin plates, thus making the skin at this point 3 in. thick.

The inner shell of the jack boxes consisted of two plates, $\frac{5}{8}$ in. thick and 4 ft. $9\frac{1}{4}$ in. long, excepting for a width of 3 ft. $11\frac{1}{4}$ in. in the center top section of the shield where the inner plate was 6 ft. $3\frac{1}{2}$ in. long to form the roof of the safety screen on the back of the shield.

At the rear end of the tail a bead, 18 in. wide and $\frac{1}{2}$ in. thick, was riveted around the inner side of the tail. It had a chamfer 3 in. wide, tapering down to $\frac{1}{4}$ in. thick at each edge. The object of this bead was to permit the shield to be steered without binding on the leading edge of the cast-iron lining. Excepting where the floors and diaphragms divide the jack boxes, they were parted by rolled I-beams, 1 ft. 10 in. by 9 by $\frac{3}{4}$ in., and stiffened by dished plate frames across each box, the rear frame being solid and the center one having a hole 1 ft. 3 in. in diameter for the jack to pass through. All plates were planed on the edges, and all bolt holes and rivet holes were drilled in place wherever possible. The rivets were 1 in. in diameter, and the rivet holes $\frac{1}{16}$ in. greater in diameter. All rivets on the outside were countersunk flush with the skin of the shield, and also on the inside of the tail behind the jack boxes; that is, where the cast-iron tunnel lining is built.

In addition to the two vertical diaphragms, there were two transverse bulkheads, 2 ft. 6 in. apart, completely closing the shields, excepting for openings which were made for doors and muck chutes. For each floor there was a pair of doors, one in each transverse bulkhead, and nine muck chutes pierced both bulkheads, with hinged doors on either end. A ladder, 2 ft. wide, passed from the top to the bottom of the shield on the outside of the right-hand vertical diaphragm, in a vertical iron ladder recess open toward the cutting edge. This was continuous through each floor. Ladders were also provided on the back of the shield for access to the doors.

Two large recesses, about 3 ft. 9 in. wide, open toward the back of the shields, were arranged, one on each side of the shield, between the

FIG. 1.—CONCRETE BULKHEAD AND AIR-LOCKS.

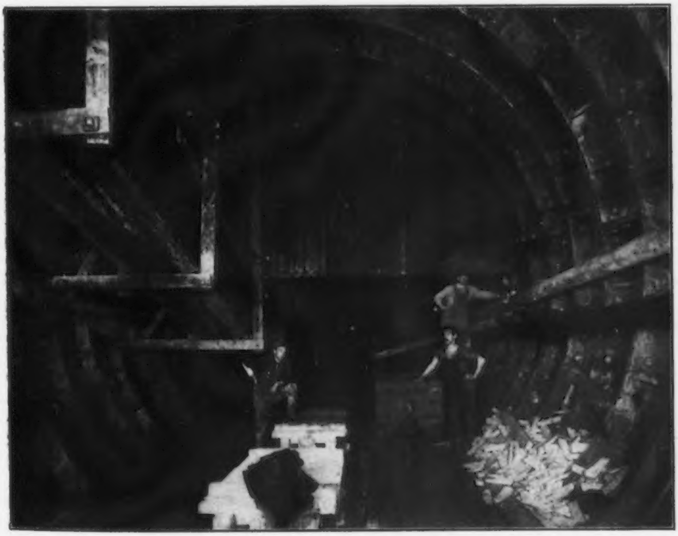


FIG. 2.—SAFETY SCREEN.

horizontal floors, in which were located all the hydraulic controlling valves and the mechanics operating them.

A safety screen, about 4 ft. wide and 7 ft. deep, shrouded and surrounded the doors opening from the upper chamber.

A drop safety curtain, 1 ft. 6 in. deep and $\frac{3}{8}$ in. thick, was fixed along the roof of each chamber, and a protecting coffer-dam, 6 in. high, was fixed along the back of each floor, both coffer-dam and curtain being on the same line, 18 in. forward of the forward transverse bulkhead; a continuous passageway opened through the vertical diaphragms for access to each pocket on each floor for the same width.

The cutting edge was of cast steel, divided into segments machined on the radial joints and bolted together with turned and fitted bolts. It was of a shape aptly described by its designer as a lark's foot, and was firmly riveted to the shell plates. The upper part of the cutting edge was especially shaped to receive a temporary fixed hood, and all segments were pierced in the circumferential web with 4-in. holes. The lower half of the cutting edge was pierced radially with tapped test holes, $1\frac{1}{2}$ in. in diameter, which also passed through the shell plates to serve as vertical test holes to find a rock ledge before it was struck by the cutting edge, and, during the tunneling operations, it was found necessary to drill holes through the shell in the roof for the purpose of grouting and also for forcing water to extinguish fires in the timbering and salt hay packing under which the shield had been shoved. Such fires were of frequent occurrence.

Struts formed of gusset plates, 1 in. thick, with stiffening angles, were also fixed at the back of each jack, not otherwise supported by the floors or diaphragms, to communicate the thrust of the jacks to the cutting edge, and a 9 by 1-in. cover-plate, was riveted inside the inner flange of the cutting-edge segments.

Two holes, 8 in. in diameter, for air supply, one 6 in. in diameter for water blow-off, one 6 in. in diameter for foul air exhaust, and one 4 in. in diameter for high-pressure air supply were cut in the bulkheads. All parts of the shield, such as bulkheads, chutes, back ends of jack boxes, etc., between the two transverse bulkheads were made air-tight.

The object of the two transverse bulkheads was to maintain a differential air pressure. By closing the doors of the forward bulkhead, air could be pumped into the shield at a higher pressure than the

pressure in the tunnel, and all the excavation could be locked through the muck chutes and the men could lock themselves between the two bulkheads by the use of the air-tight doors.

Such an arrangement would keep as few men as possible under high-pressure air, all the loading of the muck into cars, grouting, building of tunnel lining, and caulking, would be done at a lower pressure than was necessary in the face of the shield. As 37 lb. was the highest pressure ever necessary to keep the water out of the face, this was not done.

The greatest difficulty with this feature, if it had been used, would have occurred in material composed partly of rock and partly of quicksand in preventing the air pressure in front of the shield from escaping backward along the cavities in the blasted rock into the tunnel proper through the joints of the iron, and between the iron and the tail of the shield, although this would not have been insurmountable, but the small reservoir of air contained in the shield would have caused great variations of pressure in the event of "blows," and flooding would have been frequent in that case.

The benefit of having the two transverse bulkheads is to give the shield an added stiffness which it requires. The smallness of the doors and the muck chutes through these bulkheads handicapped for a time the mucking-out operations, especially in rock, and after it was found that there was no likelihood of this feature being required, the transverse bulkheads in all three bottom pockets were cut out, and the middle bottom pocket was utilized for running the tunnel cars through the shield into the heading beyond on the tunnel track.

To facilitate the passage of drill columns and timber to the upper pockets, part of the center pocket transverse bulkhead was also cut away.

The ladderway inside the shield gave access to all floors in case the differential pressure were used, and was useful for the purpose in any event. The 6-in. coffer-dam along the back of each horizontal floor, 18 in. in front of the doors, prevented sand and débris from being washed against the doors if the shield was flooded, and also kept the passageway clear.

The 18-in. curtain suspended from the under side of each floor, 18 in. in front of the bulkhead, provided an air space for the men if the shield was flooded, when they ducked their heads under this curtain.

PLATE X.
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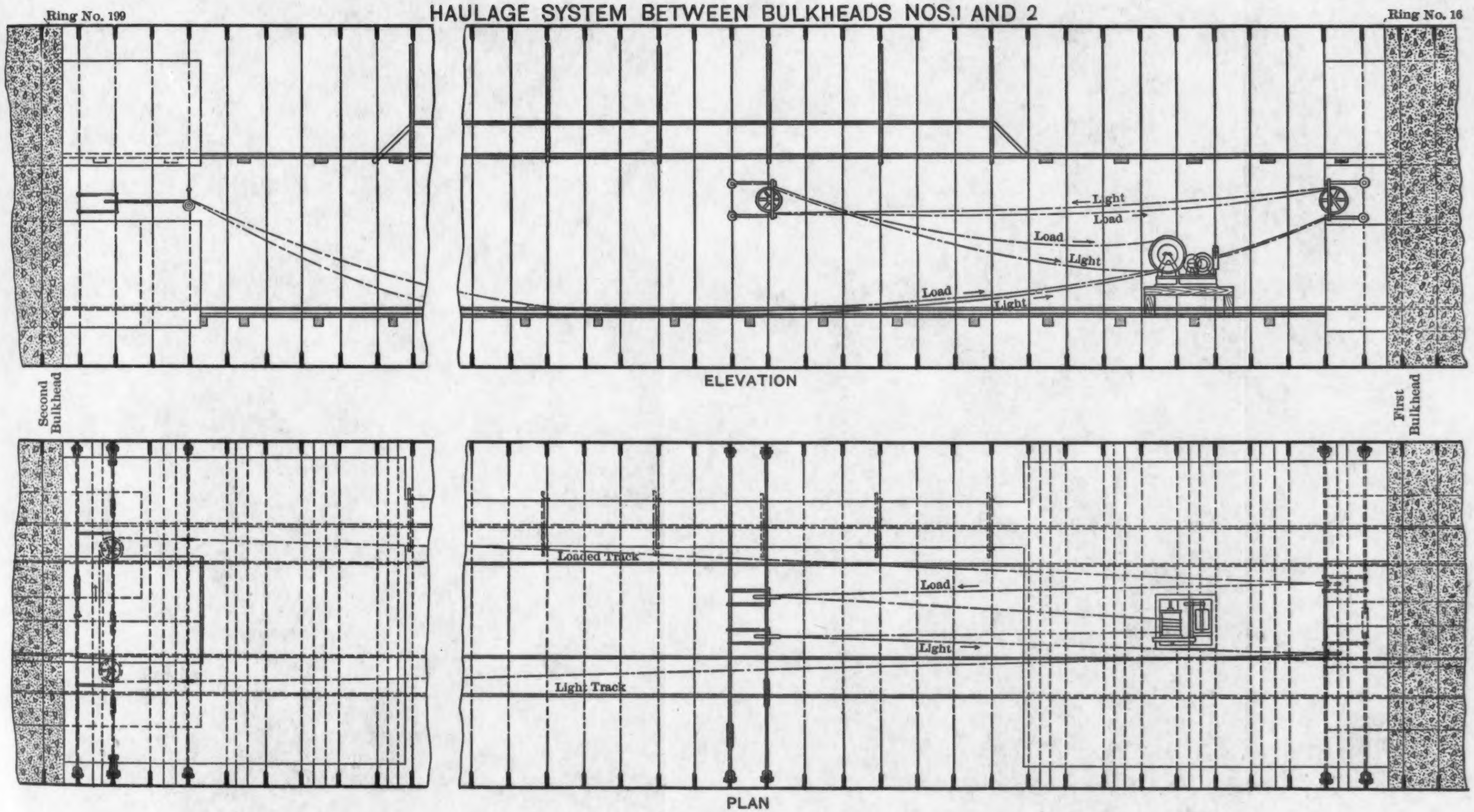
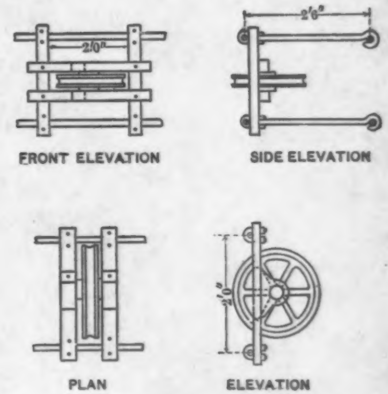
HAULAGE SYSTEM BETWEEN BULKHEADS NOS. 1 AND 2





The object of the safety screen which shrouded the door of the upper chamber was to prevent the water in the tunnel from rising more than 1 or 2 in. above the bottom of this screen, although the shield proper might be filled to the top with water. This feature was tested once and proved effective when one tunnel was flooded. This, of course, would only be true if the space between the tail of the shield and the cast-iron tunnel was pugged around the upper part of the shield down to the level of the bottom of the safety screen.

As the conditions obtaining underneath the East River had never been explored by a previous tunnel at the time these shields started work, many and varied conditions and contingencies were provided for in the accessories of the shield which would be unnecessary in future work under this river. At that time the only tunnel under the East River was the gas tunnel at a deep level below the quicksand. The Battery tunnel, it is true, had advanced far from the Manhattan shore, but had been, up to that time, entirely in solid rock. The test borings driven by the Railroad Company's engineers, acting under Mr. Noble, Chief Engineer, disclosed the level of the rock on the lines of the tunnels, but, as they were wash-borings, the nature of the soft material overlying the rock as to its air-holding capacity was somewhat doubtful.

On account of this, sliding shutters, with screw-jacks, similar to those used in the Blackwall tunnel shield in open gravel, were fitted. The details of these are shown on Plate IV. They were used without a hood. Two types of hoods were designed; one was a movable hood, shown on Plate IV,* consisting of steel poling boards lying on the outside of the shield and advanced by means of screws; the other was a fixed hood, shown on Plate V,† put up in sections. Two types of extension floors were designed and built for the shields; one was a sliding floor moved forward by hydraulic jacks, shown on Plate IV,* the other was a fixed floor.† Both types were carried away by falling rock, and were abandoned. The operation of all these accessories is dealt with in detail in the paper by Messrs. Brace, Mason, and Woodard.

The most satisfactory arrangement, in any type or mixture of types of material found under the river, was the bare shield, with the fixed hood projecting 3 ft. in advance of the cutting edge for about two-fifths of the circumference, and no extension floors except those formed

* Also shown by Fig. 1, Plate LXV, of the paper by Messrs. Brace, Mason, and Woodard, *Transactions*, Am. Soc. C. E., Vol. LXVIII.

† Shown by Fig. 2, Plate LXV, of above paper.

by sliding timber extensions, which could readily be replaced if damaged.

These sliding timber floors were built of two 9 by 9-in. timbers in each pocket, decked with 3-in. planking, held down to the floor at the rear end by 8-in. cross-timbers propped from the floor above and back-propped to the bulkhead. These sliding timbers were known by the workmen as cantilevers, and were also used for supporting the poling boards in the roof.

Braces (technically known by the workmen as "guns"), consisting of a 2½-in. pipe, filled with cement grout, sliding inside a 3-in. pipe and gripped with set-screws, were used for bracing the breasting boards. As the shield moved forward the set-screws were adjusted to give enough friction to hold the breasting boards tight while the guns telescoped on themselves. In the same way, the cantilever timbers were adjusted as to friction by wedges between the bearing timbers and the cantilevers.

Removal of Shields.—After the shields met beneath the river, it was necessary to cut them apart, leaving the skins in place, inside which the tunnel lining was built. As the labor of cutting them out had to be performed in compressed air, and represented an enormous amount of work, it was decided to burn them out by electricity.

The current for burning the shields was obtained from the Long Island City power-house, from one of the 300-kw., 250-volt, rotary converters. Occasionally, when burning one shield, only one of the steam-driven 160-kw. sets was used. The circuit for burning was taken from the positive terminal of the generator, and was conducted through a water-resistance consisting of four barrels of submerged iron plates, about 18 by 14 by ¼ in., all four barrels being connected in parallel. This resistance served to reduce the voltage to approximately 45 to 60 volts at the burning tool in the tunnel, and also for regulating the current according to the number of tools working simultaneously. From the water-resistance the current was conveyed to ground-plates submerged in the river, the total area of these plates being about 48 sq. ft. From the negative terminal of the generator, a cable was run to the shields direct, branching off at the shafts, one branch going down Tunnel *D* and the other down Tunnel *B*. A connection was made to Tunnels *A* and *C* from Tunnels *D* and *B* through a small pipe driven between the two tunnels. The cables used were 500 000 cir. mils, and the capacity was about 650 amperes.

PLATE XI.
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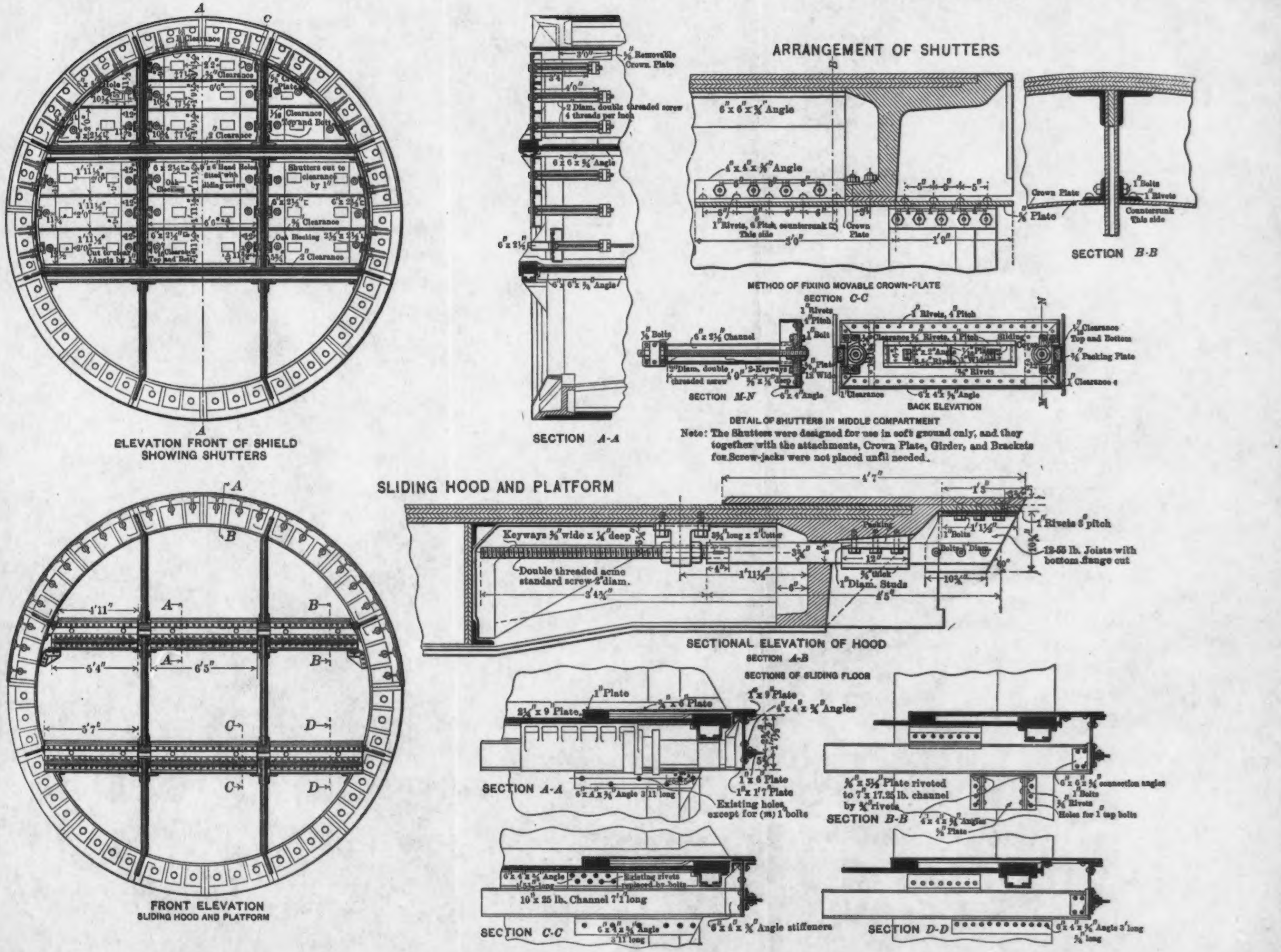

The burning tool consisted of a carbon 12 in. long and 1 in. in diameter bolted to a copper rod. This copper rod was connected to the cable leading directly from the generator to a single-pole switch near the shields. The tool was provided with an insulated handle and a shield of asbestos, 12 in. in diameter, for protecting the hands of the workmen from exposure to the light. The men were also protected by an asbestos mask, with dark-colored eye-glasses, and an asbestos apron.

The current consumed for burning the shields varied from 250 to 400 amperes per tool for burning off rivet heads and for light section plates, while from 600 to 800 amperes were required for burning through the floor plates and uprights, the uprights being about 4 in. thick. The best results were obtained with about 40 volts at 600 amperes, the arc being from ½ to ¾ in. long.

To cut off 300 rivet heads was considered a fair 8-hour shift's work; 530 rivet heads was the highest record. One man, who was specially expert, cut off one upright in 8 hours, the amount of metal being approximately 4 ft. 6 in. by 4 in.

Several of the workmen cleaning up the tunnel some distance away from the burning were blinded by the light. It takes but a few seconds, looking directly at the arc, to cause one to turn blind temporarily a few hours later, and causes violent headaches.

Dense fumes arose from the burning metal, which for the most part were carried off directly by a foul-air blow-out pipe suspended near the arc, but great quantities escaped into the tunnel, and it was often so dense that one could walk along the lighted tunnel with difficulty by the aid of a candle. No specially high CO_2 was recorded on account of this, and no bad cases of "bends" occurred in this foul atmosphere, although the air pressure was 29 lb.

Light-Section Shields.—The shields of a lighter section were designed for the work carried out under air pressure at East Avenue. The first one, which was made from an old London tube shield, was unable to stand the weight of earth above it, on account of being in rock for half the diameter. The large annular space between the outside of the shield and the jagged edges of the rock excavation gave it no reaction to resist the downward pressure of the earth in the top.

Fig. 13 shows the light-section shield, which was made for the work under compressed air under the Long Island Railroad depot. This was none too strong in the rock section with soft top, but

answered its purpose quite successfully. It will be noticed that the back of the shield is quite open, although a light stiffened diaphragm was available for bolting on it if flowing material were met. This shield was built and dismantled in three tunnels, namely, *D, C,* and *A*, East Avenue.

Each shield was fitted with 27 hydraulic jacks (Plate V) 9 in. in diameter with 3-ft. stroke for the subaqueous shields, and 8 in. in diameter for the light-section shields. The head of the jack was offset 10½ in. from the center, and was beveled off so that the pressure would be transmitted to the cast-iron tunnel lining on the circumferential web, instead of on the circumferential flange. The cylinders of the jacks were of solid forged steel.

Each jack was tested to a pressure of 9 000 lb. per sq. in. with the ram in position, but the head of the ram, not being strong enough to withstand an offset pressure of this amount, was held centrally. They were machined so that when the cylinder was up-ended and the ram inserted it fell gently of its own weight into the cylinder, all the waterways being open.

In operating the first shields, great trouble was experienced in keeping the draw-back spindles tight, and it was found that the **U**-leathers were cutting very quickly, partly due to the poor quality of the leather and partly to the fact that the brass backing ring was too loose on the draw-back spindle and allowed the pressure to force part of the leather into the annular space between the backing ring and the spindle. Imported **U**-leathers were then used, and they lasted somewhat longer. Woodite was very little better, and ultimately Dermatine, an imported substitute, was found to be most successful. Dermatine seems to be built up with rubber and silk. Previous to its use, pieces of the damaged **U**-leathers got into the waterways, and very soon choked the passage of the water.

To help the lubrication, 5 lb. of soft soap were put in the hydraulic water tank for each shove made, and in the winter the water was heated by steam to prevent freezing.

Much trouble was also caused at first by very fine quicksand being sucked through the small opening in the cast-iron plug into the internal bore of the ram. This was obviated by putting a small non-return valve in the opening, which allowed any leakage to escape but prevented any dirty water from being sucked into the draw-back. Owing to the large

PLATE XII.
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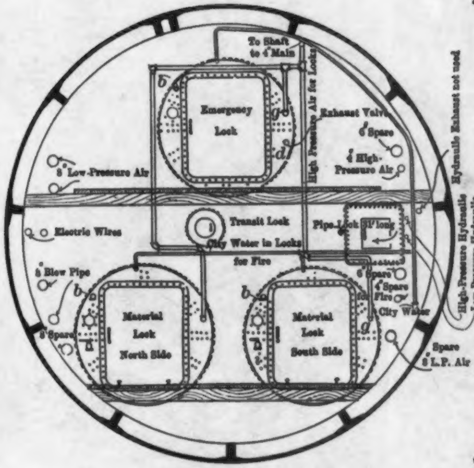
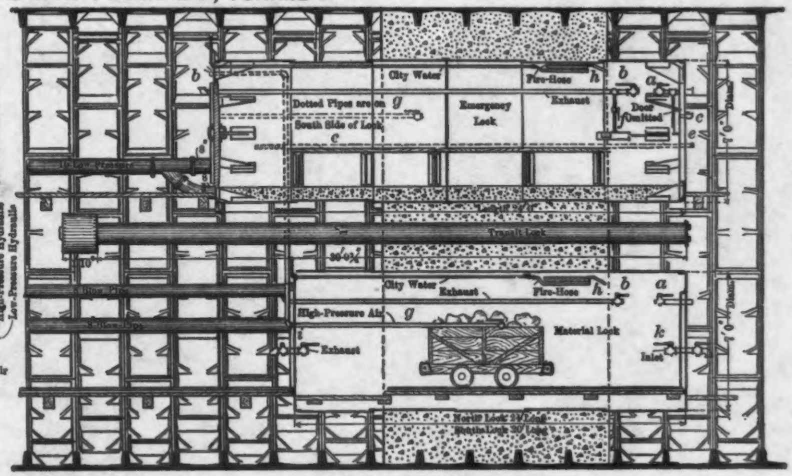
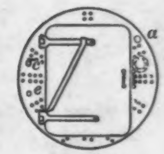
LOCKS IN NO. 1 BULKHEAD, TUNNEL *A*



FRONT ELEVATION

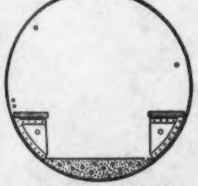


SECTIONAL ELEVATION
ALSO INSIDE OF MATERIAL LOCK

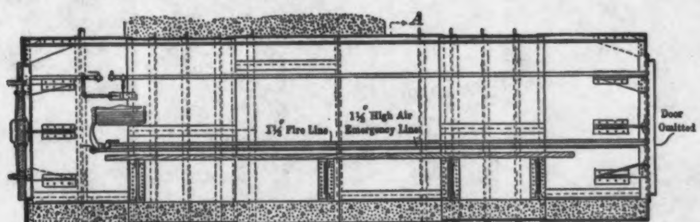


END VIEW OF EMERGENCY LOCK

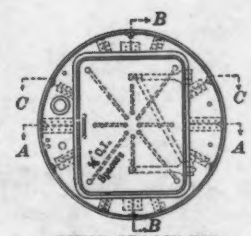
DETAILS OF AIR-LOCKS



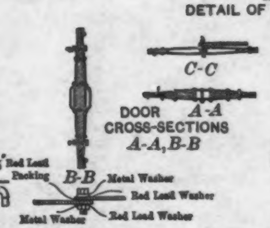
CROSS-SECTION
A-A



SECTIONAL ELEVATION OF MAIN LOCK - LOOKING SOUTH

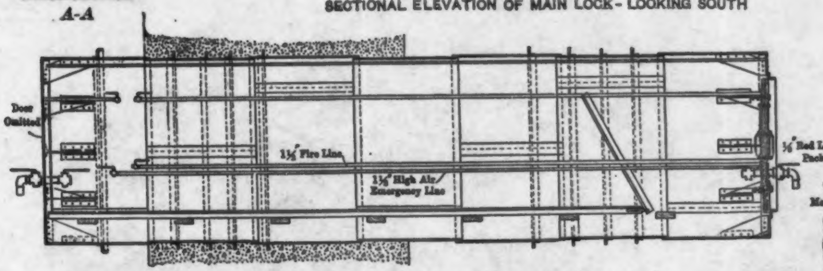


DETAIL OF LOCK END

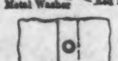


DOOR CROSS-SECTIONS
A-A, B-B

DETAIL OF HINGES



SECTIONAL ELEVATION OF MATERIAL LOCK—LOOKING SOUTH



DETAIL-SPLICE OF LOCK PLATES

offset pressure on the ram head and the softness of the steel, both of the cylinder and of the ram, it was found that they were cutting into each other and ultimately cutting so deeply as to defy all movement. It was found, on taking out the first damaged ram, that a piece of steel as big as a $\frac{3}{4}$-in. rivet head had been torn out of the ram and smaller pieces from the cylinder. These portions were analyzed, with the following results:

	Ram of shield jack.	Cylinder of shield jack.
Carbon	0.41%	0.47%
Manganese	0.57%	0.50%
Phosphorus	0.02%	0.016%
Silicon	0.009%	0.019%
Sulphur	0.045%	0.038%

Mr. A. W. Gibbs, General Superintendent of Motive Power of the Pennsylvania Railroad Company, whose chemist, C. B. Dudley, M. Am. Soc. C. E., made the analysis, suggested that the silicon should have been about 0.20%, and, as there were no shock strains, a steel considerably higher in carbon, viz., 0.60 to 0.70%, would give much more successful results.

The seizing of these rams was quite a serious matter, and, in order to get them repaired, it was necessary that the ram and the cylinder in which it was jammed be pulled out of the shield. To do this, one plate was left out of the ring opposite the damaged jack, and, on shoving 2 ft., the jack, being lashed to the tunnel lining, was left behind and removed, and the plate was pushed into place.

The method adopted for repairing was to machine the damaged part of the ram in the lathe down to 8 in. in diameter for a distance varying from 9 to 18 in., depending on the extent of the damage, and bush this with a hard gun-metal sleeve. When this was done, no further trouble was experienced, and, after the work was finished, the bushed rams showed no signs of seizing.

As the bush in most cases came outside the gland of the ram, on a full shove it was necessary to make it water-tight, so that the hydraulic pressure could not get under the bush and burst it when it came outside the gland.

The jacks were coupled up in pairs to the controlling valves (Fig. 14) in the valve chambers. Each valve consisted of three steel

conically-ended spindles seating on the gun-metal body of the valve, which had four connections. One spindle controlled the high-pressure water from the main, while, of the remaining two, one controlled the exhaust and the other the admission of water to the rear end of the ram.

The draw-back waterway was under pressure as soon as the spindle controlling the pressure was opened, so that, assuming that all was in readiness for shoving, the spindle controlling the pressure being opened, and the exhaust shut, the operator, on opening the third spindle, allowed water to pass to the back of two rams which moved forward, the water at the back of the draw-backs circulating to the main.

Depending on the direction in which it was desired to guide the shield to maintain the engineer's lines, the jacks, in pairs on either side of the shield, were opened up, and also in pairs, top or bottom of the shield, depending on the grade required.

In order to stop all the jacks simultaneously, to prevent overshoving, it was usual to open a by-pass on the high-pressure main; this reduced the pressure sufficiently to stop the shield. The spindles controlling the admission of the pressure to the back end of the jacks were then shut for each pair, and, after telephoning to the power-house to slow down the hydraulic engine, the by-pass was closed and the rams were drawn back in pairs by opening the exhaust spindle. A pressure of 2 000 lb. was sufficient to draw back the rams, and if more was required it was a sign that the rams were scoring, or that the draw-back leather required renewing. If they failed to draw back, they were pushed home with a small portable hydraulic jack. Copper pipes, ½ in. in diameter, were used for coupling the valves to the jacks and ¾ in. in diameter for the draw-back; and all the waterways in the jacks and draw-back spindles were ½ in. in diameter.

Erectors.—Two hydraulic erectors (Fig. 15*) were fixed on the back of each subaqueous shield. On the light-type shield the erector was fixed on the traveling stage. These were used for building the cast-iron tunnel lining. They consisted of an arm, which could be extended, and at the same time rotated. The extension was accomplished by a hydraulic cylinder, 4½ in. in diameter, with a piston of that diameter attached to a ram 3 in. in diameter passing through a gland at one end of the cylinder, the piston being fitted with a leather

* Shown also by Fig. 1, Plate LXVI, of the paper by Messrs. Brace, Mason, and Woodard, *Transactions*, Am. Soc. C. E., Vol. LXVIII.

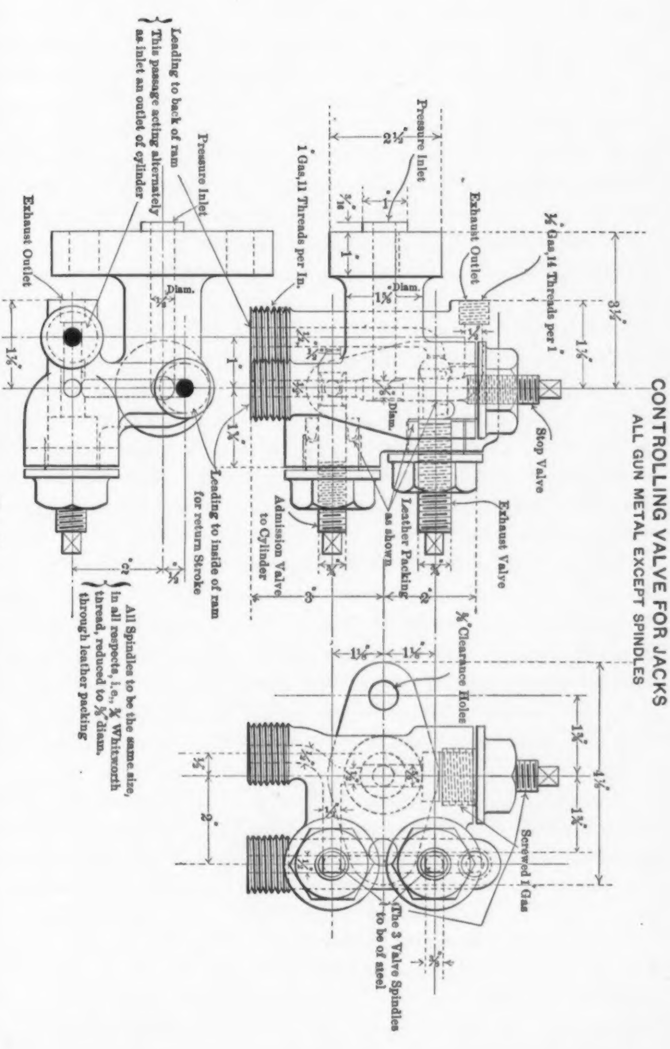

CONTROLLING VALVE FOR JACKS
ALL GUN METAL EXCEPT SPINDLES
Stop Valve
Exhaust Valve
Leather Packing as shown
Admission Valve to Cylinder
Gas, 14 Threads per 1"
Exhaust Outlet
Pressure Inlet
1" Gas, 11 Threads per In.
Diam.
Leading to back of ram
This passage acting alternately as inlet an outlet of cylinder
Pressure Inlet
Exhaust Outlet
Leading to inside of ram for return Stroke
All Spindles to be the same size, in all respects, i.e., Whitworth thread, reduced to diam. through leather packing
Clearance Holes
Screwed 1" Gas
The 3 Valve Spindles to be of steel

FIG. 14.

which acted only on the backward stroke, or the equivalent of a ram 3 in. in diameter acting in either direction.

Bolted to the plunger by a cast-iron bracket was an I-beam, 9 ft. 6 in. long and 11¼ by 5 in., the web extending 7 in. beyond the flanges at one end. This extension was reinforced by two ½-in. plates and pierced with an oblong hole, 5 by 1¾ in. The I-beam slides, with a stroke of 6 ft. 0 in., in a guide-box which is held in one end of a rotating casting by a 1½-in. pin on which it hinges, and on the other end by two spherical washers with elliptical holes on the end of an adjustable spindle, screwed into the slide-box. An internal-screwed spindle holds the outer washer to jam the slide-box at the required angle.

This allows the erector to be adjusted if the shield has been shoved too far, or if working with an excessive lead.

The cast-iron rotating piece is bolted to a cast-steel pinion having a pitch circle of 20 in. The arm with the pinion is rotated by a rack on the 8⅛-in. plunger of the 11½-in. slewing cylinder, which has a piston 11½ in. in diameter. The piston has a leather which acts on the upward stroke only, or the equivalent of a ram 8⅛ in. in diameter working either way.

The erectors are controlled by a two-way slide-valve, shown on Plate VI. The pressure enters on the upper side of the slide and passes directly to the under side of the slewing cylinder. If the slide-valve is moved over so that the upper end of the cylinder communicates with the exhaust port, the ram moves upward and the erector rises, but, if the slide is set so that the upper end of the cylinder communicates with the pressure, the ram moves downward, the water on the under side of the piston circulating through the valve-box to the main.

With a similar valve, the push-and-pull cylinder on the rotating arm was controlled. The connection to this cylinder was made by two flexible, armored-hose pipes, leaving the erector free to rotate. Water was admitted to the erectors through a safety, non-return, stop-valve, shown on Plate VI, so that, if the pressure failed, the erectors would not fall. These erectors were designed to handle segments weighing 1 ton each, with a pressure of 1 000 lb. per sq. in. To accelerate their movement, the pressure was ultimately raised to 1 200 lb. This was simpler than increasing the diameter of the openings in the valves and pipes. The erector arm was attached to the tunnel segments by a gadget (Fig. 15).

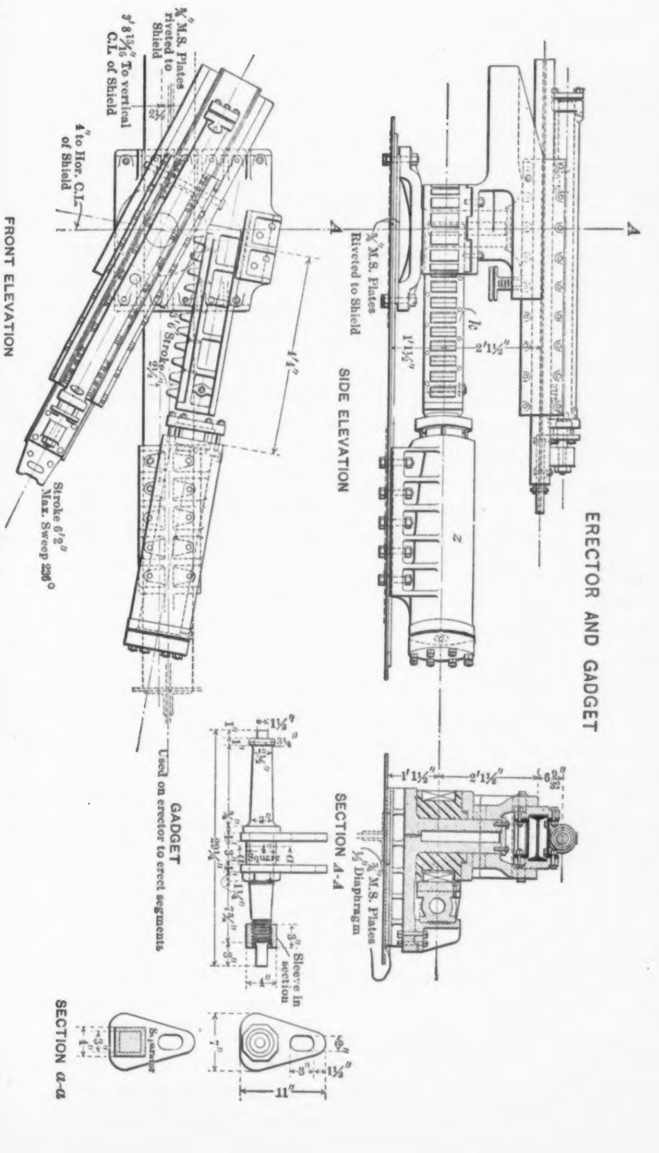

ERECTOR AND GADGET
SIDE ELEVATION
FRONT ELEVATION
SECTION A-A
GADGET
Used on erector to erect segments
SECTION a-a
Stroke 6' 2"
Max. Sweep 236°

FIG. 15.

Behind each shield a traveling platform (Fig. 16), 46 ft. long and 20 ft. 6 in. wide, on twelve rollers, 12 in. in diameter and 12 in. long, running on 60-lb. rails, supported by steel brackets bolted on every second ring to the circumferential flanges of the tunnel lining, was attached by two union screws to each shield, and was pulled along by it during each shove. The stage was double-decked. On the upper deck the cement and sand for grouting were stored, and a cantilever extension in front was used for bolting up the iron; on the lower deck the grout-mixing machines were fixed. It was originally intended to use these stages for taking care of the excavation, so that it could be handled from two levels, but the output was never large enough to require this, as casting the excavation directly into cars on the floor of the tunnel sufficed.

A hydraulic elevator at the rear end of the stage, for raising cement and sand, and an air-winch at the forward end, for hoisting lumps of rock into the cars, were the only mechanical attachments, excepting in the case of Tunnel *A*, Manhattan, where a belt conveyor was tried, as shown on Fig. 16, under the stage, and by Fig. 2, Plate I. The rails on which it traveled were in 6-ft. lengths, spanning two brackets and bent down at the rear end to catch the brackets.

Rock Drills.—The standard Ingersoll, *E* 52, $3\frac{1}{4}$-in. rock drill was adopted, after testing various makes. They were found to use less air than other makes and to stand up to the work equally well, if not better. They had exceptionally hard service on account of the seamy nature of the rock. They were generally mounted on Standard drill columns, set up in the pockets of the shield, except when advance headings were being driven.

In addition, for small trimming work and for breaking up lumps of rock, little Jap drills, $1\frac{1}{4}$ in. in diameter with 4-in. stroke, and *M V* drills, $1\frac{11}{16}$ in. in diameter with $2\frac{1}{4}$-in. stroke, made by the same company, were used.

For rust and lead caulking, Boyer and Keller hammers, $1\frac{1}{16}$ and $\frac{15}{16}$ in. in diameter, made by the Chicago Pneumatic Company, giving 2 800 blows per minute, were found most effective; and, for drilling junction segments, etc., Little Giant rotary pneumatic drills were used.

Grouting Pans.—The grouting pans, Fig. 1, Plate VII, were of the Greathead type, made mostly by the Cockburn Barrow Company, driven by 3-cylinder Ingersoll air-motors, the air-motor being geared to the

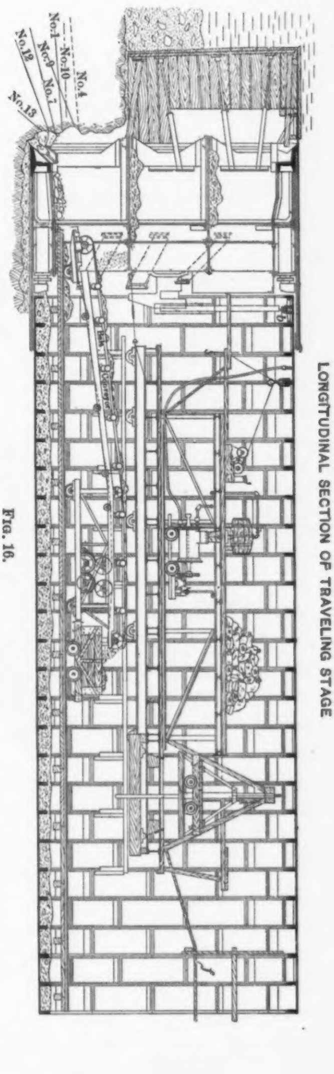

LONGITUDINAL SECTION OF TRAVELING STAGE
No.4
No.1
No.10
No.9
No.7
No.12
No.13

FIG. 16.

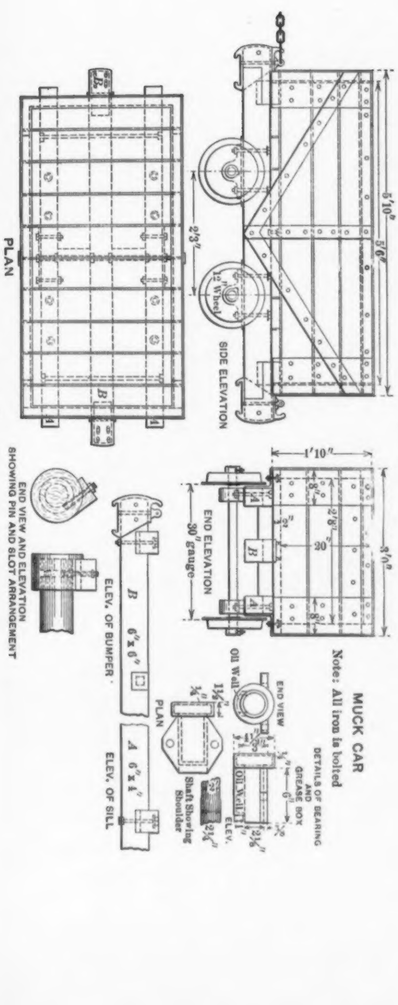

MUCK CAR
Note: All iron is bolted
SIDE ELEVATION
PLAN
5'10"
5'6"
2'3"
12" Wheel
END ELEVATION
30" gauge
1'10"
3'0"
DETAILS OF BEARING AND GREASE BOX
END VIEW
ELEV.
PLAN
Oil Well
Shaft Showing Shoulder
ELEV. OF BUMPER
B 6"x 6"
ELEV. OF SILL
A 6"x 4"
END VIEW AND ELEVATION SHOWING PIN AND SLOT ARRANGEMENT

FIG. 17.

central spindle which rotated the beaters or mixing blades. The air-motor was kept revolving during grouting operations, and, after half filling the pan with water, the mixture of sand and cement was dumped into the pan, and, the small hinged door on the top being pulled upward, air pressure was turned on, which held the door tight and the charge was then ejected through a flexible, armored-hose pipe coupled up to a grout hole in the tunnel lining, there being one of these in every segment. After the pan was emptied, the air pressure was shut off and an exhaust valve was opened. This emptied the pan of pressure and allowed the door to open inward, ready for a fresh charge.

The grout pans were located on the traveling stage, and were mounted on wheels of 30-in. gauge, so that they could be hauled along the tunnel tracks, and taken on top for repairs. To save time in charging them with water, a barrel with a 3-in. cock was fixed on the upper platform, so that water could be collecting there while the pan was discharging.

Muck Cars.—The muck cars, Fig. 17, were 24-cu. ft. wooden cars. The wheels were loose on the axles, and the axles loose in the pedestals. This made it very easy to get them around sharp curves, but the final result was not good, as the bushing of the wheels wore on the axles so that they wobbled and permitted the cars to get off the tracks.

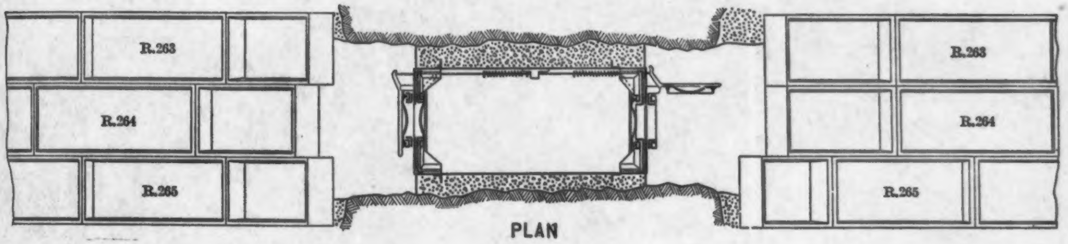
All the ironwork of the cars was made by the Atlas Car Manufacturing Company, and the cars were built on the tunnel works.

The rails in the tunnels were of Carnegie steel section, 25 lb. per yd.; 56-lb. rails were used in the yards. The gauge was 30 in. in the tunnels and 4 ft. 8½ in. in the yards.

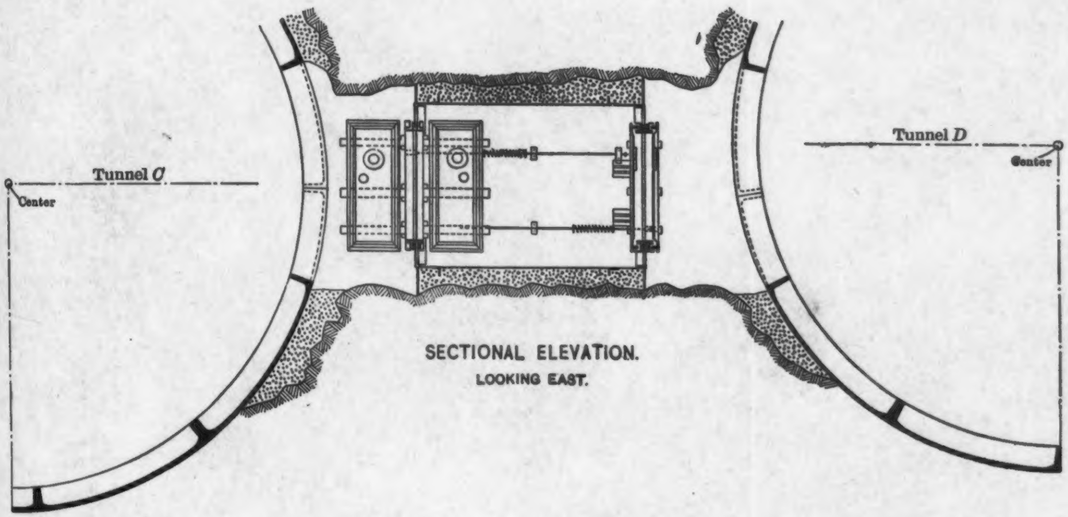
A decking was laid in the tunnel, about 3 ft. 9 in. from the under side of the iron, consisting of cross-byats, 12 by 6 in. and 17 ft. long, spaced 5 ft. apart, and longitudinal planking 5 ft. long and 2 in. thick. A bridge of built-up rails was used to conduct the center track into the middle pocket of the shield. This could be lifted during shoving.

Haulage Gear.—For the haulage of tunnel cars on the Manhattan side, four haulage gears, Fig. 2, Plate VII, were built by the Exeter Machine Works. The requirements were that each haulage gear should be able to handle a wire rope 5 000 ft. long, that is, with a haulage of 2 500 ft., and be able to take 12 loaded tunnel cars, each of 3 700 lb., up an incline of 1½%, and at the same time convey empty cars, or flat cars, loaded with cast-iron segments down the incline.

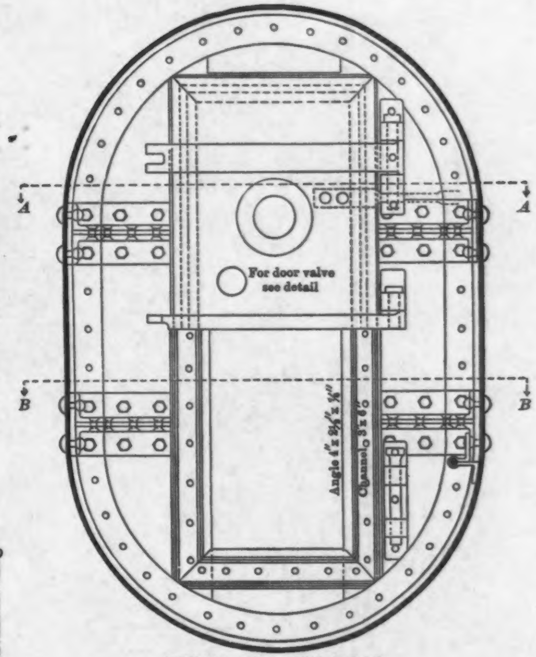
DETAILS OF CROSS-PASSAGE AIR-LOCK C-D



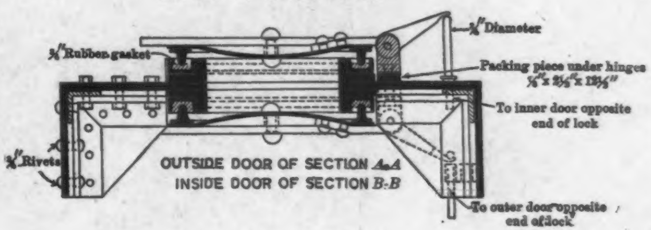
PLAN



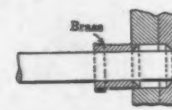
SECTIONAL ELEVATION.
LOOKING EAST.



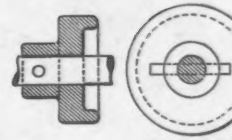
DETAIL OF LOCK DOOR.



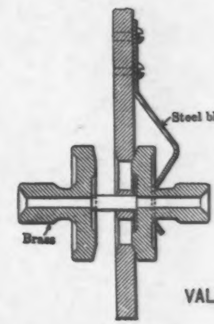
OUTSIDE DOOR OF SECTION A-A
INSIDE DOOR OF SECTION B-B



STUFFING-
PASSING ROD THROU

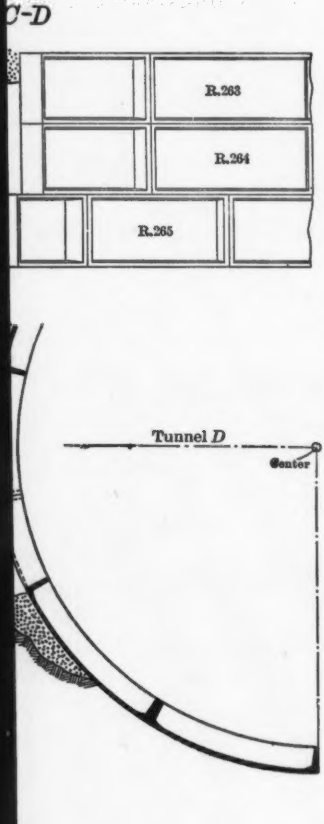


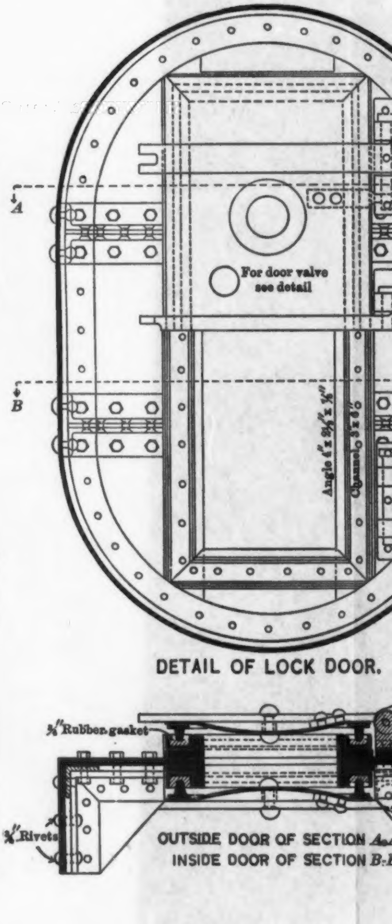
STEEL SP



VALVE

INSIDE E

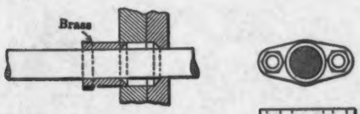




DETAIL OF LOCK DOOR.

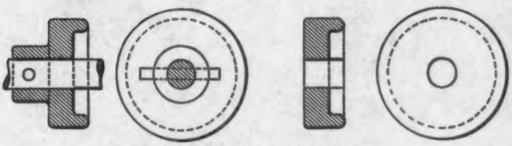
OUTSIDE DOOR OF SECTION A-A
INSIDE DOOR OF SECTION B-B

PLATE XIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1160.
JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

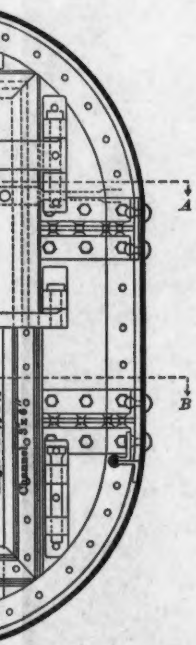


STUFFING-BOX.

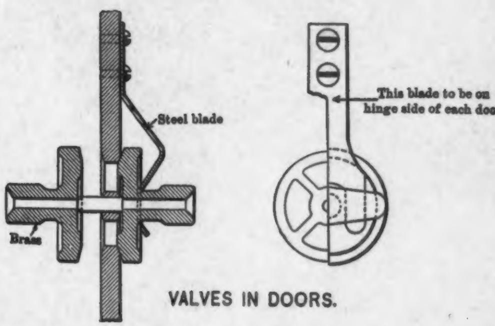
PASSING ROD THROUGH DOORS.



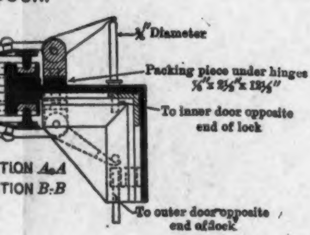
STEEL SPRING PLATES.

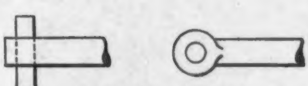


DOOR.



VALVES IN DOORS.





INSIDE END OF ROD.

The attachment between the car and the rope was made with portable grips which were hitched to the bumper of the car, and tripped automatically when the cars reached the air-locks, or the elevators. The rope, at first, was ½ in. in diameter, but was ultimately increased to ⅝ in.

The electrically-driven haulage engine was originally to be stationed in atmospheric air, and the rope was to be depressed under the floor in front of the air-locks, pass through a stuffing-box in the air-tight bulkhead below each air-lock and rise to the floor level again inside under pressure. The motor was a 30-h.p. Crocker-Wheeler motor, running on a voltage of 220, of slow-speed type, controlled by a starting rheostat.

The motor, through a countershaft, drove a drum 42 in. in diameter, with six machine-cut grooves for a ½-in. steel cable. In line with this drum was an idler drum having four grooves which were in four independent, sliding, cast-iron rings; any stretching of the rope was accommodated by the slipping of these rings, so that there was no grinding of the rope on the cast-iron surface due to unequal speeds of different parts of the rope.

The rope led over a 42-in. grooved sheave which was supported on a traveling tension carriage running on a track in the roof of the tunnel. At the end of the track a weighted tension rope passed over a sheave and kept the haulage rope at any degree of tightness desired.

Trouble was experienced with the friction caused by the rope dipping under the floors so often, and it was not found practical to operate the haulage rope in different air compartments from one engine. In the final arrangement, Plate VIII, the engine was mounted in the compressed-air chamber with one part of the rope leading over the tension carriage and back to a sheave over the right-hand muck lock, Fig. 1, Plate IX, and from there down the tunnel to a sheave under the right-hand forward end of the traveling stage behind the shield. It there passed across the tunnel to a sheave on the left-hand side of the stage and back along the tunnel to a sheave above the left-hand air-lock, and from there was guided to the haulage gear.

The rope was allowed to slide along the floor, supported on rollers to lessen the friction.

Portable grips of many types were tried, but without success, and finally a light ¼-in. chain, with a large square hook on one end which

hooked over the end of a car while the chain was caught around the haulage rope with a half hitch, proved to be the simplest and most effective method, but it entailed the stopping of the haulage gear for the attachment and detachment of each train of cars.

Inside each bulkhead a small Lidgerwood 7½-h.p. electric or air-hoist was fixed as a stand-by, with a tail-rope which could be drawn down and hitched to the cars if the haulage gear were out of commission. For short distances of 500 ft. between bulkheads a slightly larger double-drum winch, of 10 h.p., either air or electric, Plate X, was installed; and, to give a better grip and prevent cutting the drums, cast-steel liners, having a fillet radius of some 6 in., were fixed on the driving drum for the continuous wire rope, which had about four turns on the cast-steel liner, and was led in the same way as the rope from the main haulage engine.

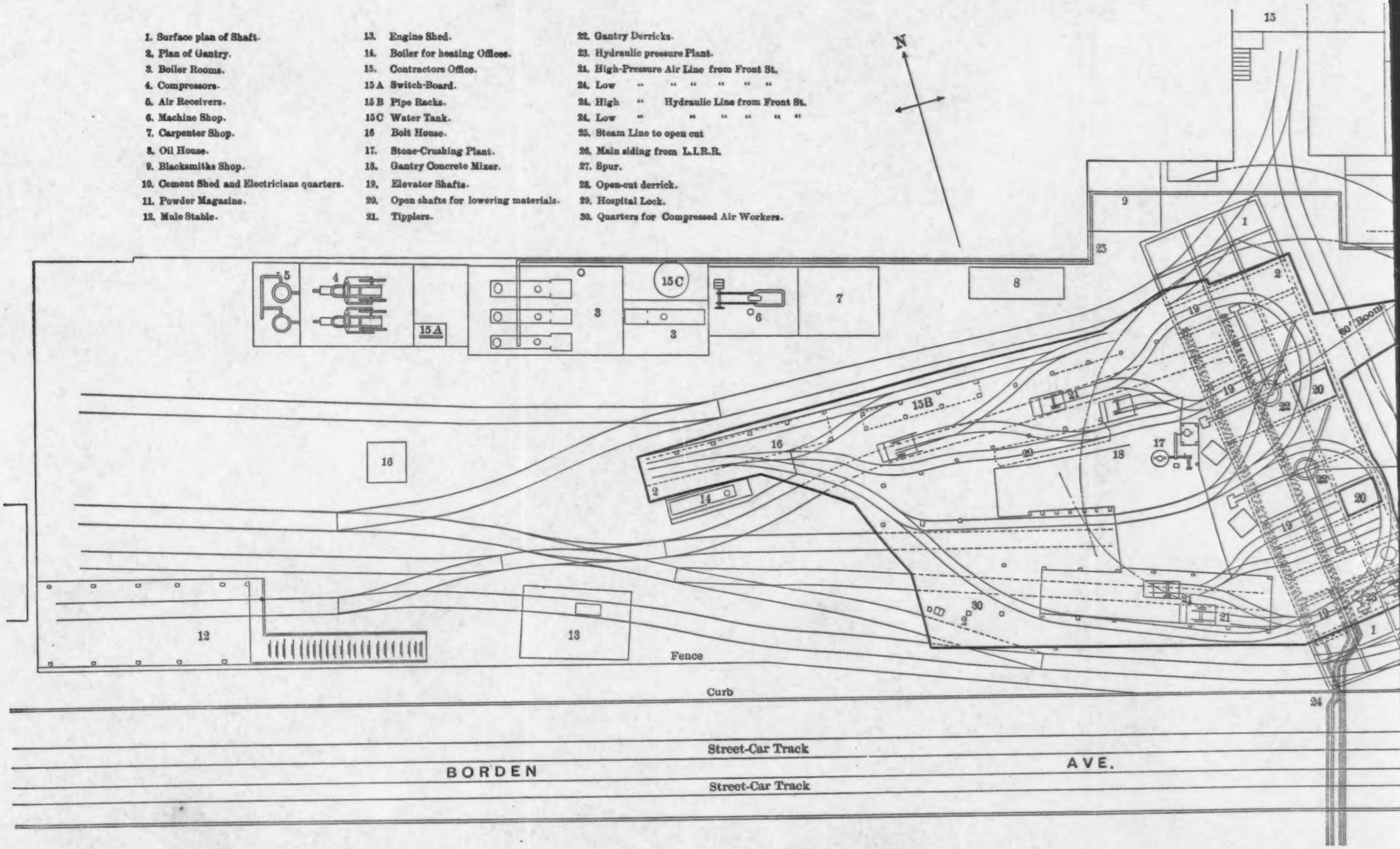
At Long Island City, for the long haul, the Lidgerwood electric hoisting engines, which had been used at East Avenue for the elevators in the shaft and were by that time at liberty, were fitted up as haulage engines, along with two spare ones, by putting a 6-in. fillet around one end of the drum made in sections; the rope, having three turns around this, was led in the same manner as before.

The speed of these hoists was reduced to give a haulage speed of about 3 miles per hour, and the Exeter Machine Company's haulage gears were speeded up from 1 mile to 3 miles an hour.

The haulage in the Manhattan yard was originally done by mules, but the difficulty of getting them about in winter, with heavy loads, and snow and ice on the tracks, made it necessary to install mechanical haulage.

It was determined to try electric haulage, and one of the under frames of the 4-yd. cars was mounted with a pair of axles having steel wheels; then a 15-h.p. electric motor, 250 volts, was fixed on the carriage, gearing to a countershaft on which were two sprocket wheels. A sprocket wheel was also fixed on each axle, and these were driven by chain from the countershaft. A sufficient quantity of cast-iron turnings was put in the bed of the car to give the required tractive effort, and two overhead trolley wires were fitted, the pole having two trolleys insulated from each other.

This method was adopted in preference to bonding the rails, on account of the impracticability of grounding the rails when they


1. Surface plan of Shaft.
2. Plan of Gantry.
3. Boiler Rooms.
4. Compressors.
5. Air Receivers.
6. Machine Shop.
7. Carpenter Shop.
8. Oil House.
9. Blacksmiths Shop.
10. Cement Shed and Electricians quarters.
11. Powder Magazine.
12. Mule Stable.
13. Engine Shed.
14. Boiler for heating Offices.
15. Contractors Office.
15 A Switch-Board.
15 B Pipe Racks.
15 C Water Tank.
16 Bolt House.
17. Stone-Crushing Plant.
18. Gantry Concrete Mixer.
19. Elevator Shafts.
20. Open shafts for lowering materials.
21. Tipplers.
22. Gantry Derricks.
23. Hydraulic pressure Plant.
24. High-Pressure Air Line from Front St.
24. Low " " " " " "
24. High " Hydraulic Line from Front St.
24. Low " " " " " "
25. Steam Line to open cut
26. Main siding from L.I.R.R.
27. Spur.
28. Open-cut derrick.
29. Hospital Lock.
30. Quarters for Compressed Air Workers.
N
80' Boom
Fence
Curb
Street-Car Track
Street-Car Track
BORDEN
AVE.

22. Gantry Derricks.
23. Hydraulic pressure Plant.
24. High-Pressure Air Line from Front St.
24. Low " " " " " "
24. High " Hydraulic Line from Front St.
24. Low " " " " " "
25. Steam Line to open cut
26. Main siding from L.I.R.R.
27. Spur.
28. Open-cut derrick.
29. Hospital Lock.
30. Quarters for Compressed Air Workers.

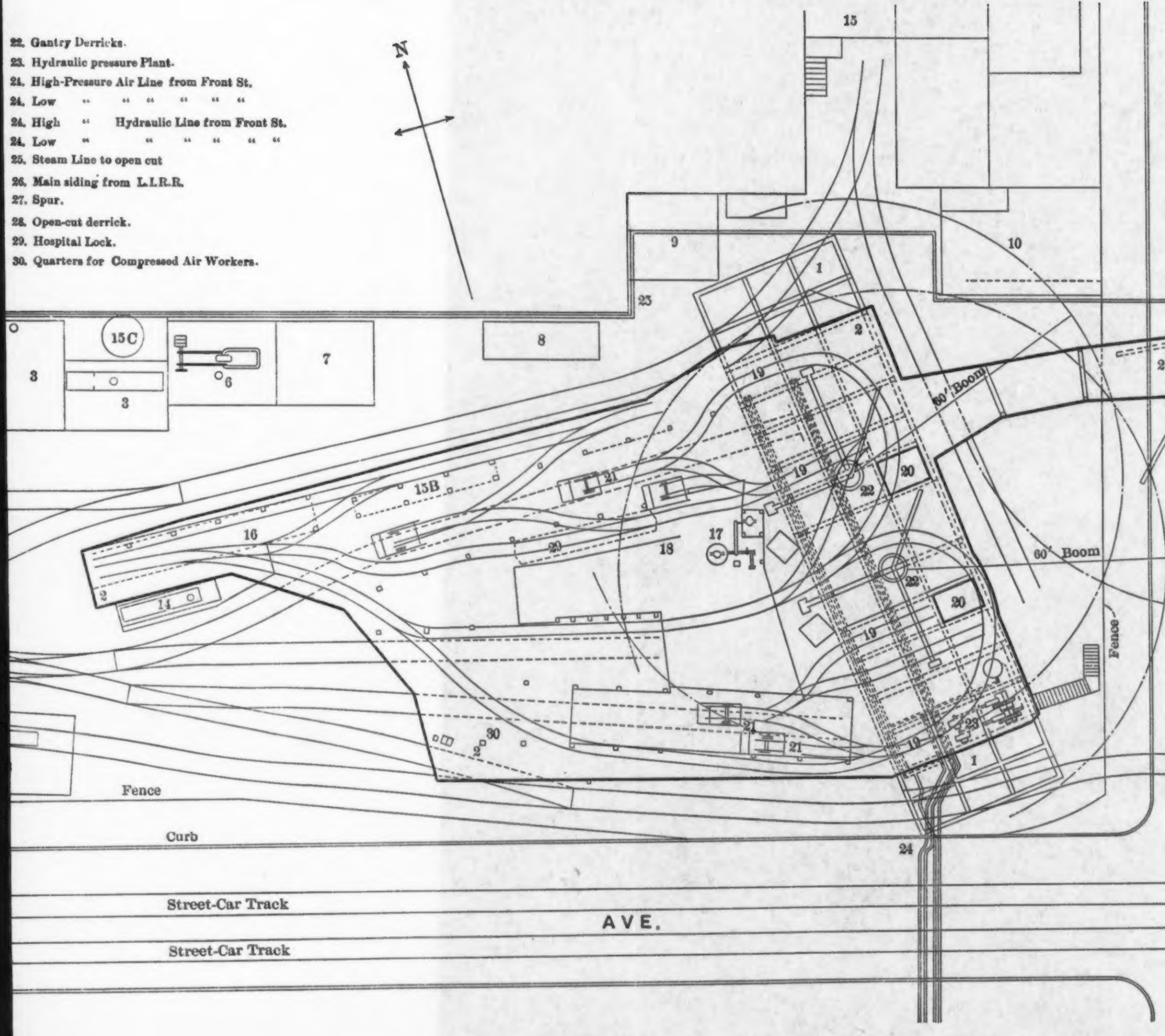


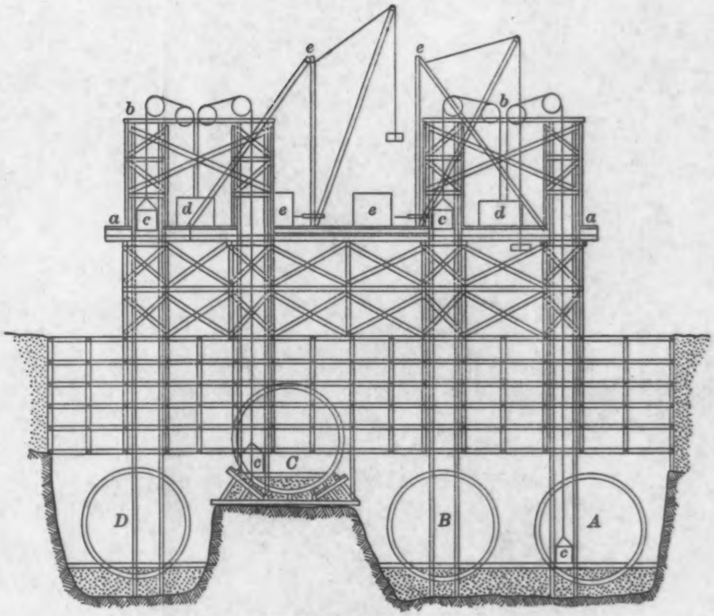
PLATE XIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1160.
JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

CONTRACTOR'S PLANT

AT EAST AVE.
LONG ISLAND CITY.

A, B, C, D indicate position of Tunnels at West side of shaft.

a Gantry Floor.
b Elevator Frames and gear.
c Cages.
d Elevator Hoist Houses.
e Gantry Derricks and Winches.



SECTIONAL ELEVATION THROUGH EAST AVE. SHAFT.
LOOKING WEST.

formed part of the lighting system in the tunnels. Two of these cars were made and were very successful.

On the Long Island side, on the surface, where there was ample room, steam locomotives were used, and also at East Avenue. These were made by the Baldwin Locomotive Works, and were of 4 ft. 8½-in. gauge and 5-ft. wheel base, with two 10-in. cylinders having a 16-in. stroke, and four driving wheels, 32 in. in diameter. Steam at a pressure of 160 lb. was generated from 350 sq. ft. of heating surface with 9 sq. ft. of grate area. The total weight in working order was 42 500 lb. The fire-box was of copper and the tubes were of brass. For hauling the concrete in the tunnels, electric traction was adopted.

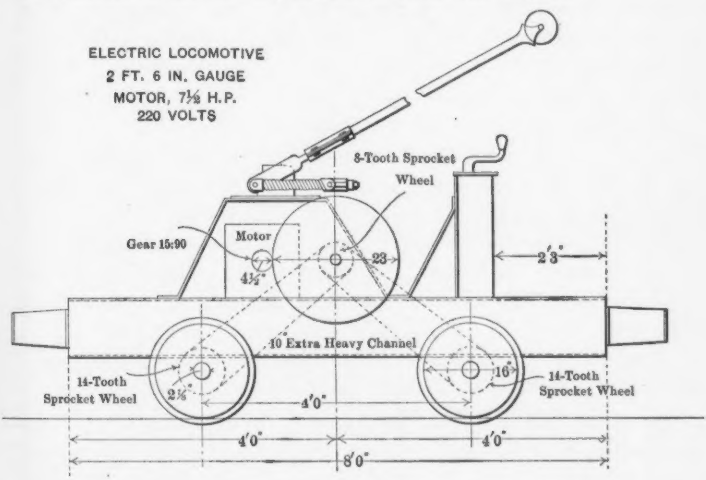


FIG. 18.

Small trolley cars, Fig. 18, 30-in. gauge and 4-ft. wheel base, were built in the tunnel workshop, and a 7½-h.p. motor was mounted, as already described; but, in this case, the rails were bonded, and only a single trolley wire, No. 2, B. & S., of hard-drawn copper was used, the current being supplied from an independent circuit operated by a motor generator of 30 h.p. Each trolley car weighed approximately 3 300 lb. In the writer's opinion, electric traction is more efficient than any other for tunnel work.

Safety Screens and Flying Gangway.—Although the safety screen behind the shield fulfilled the requirements of the specifications to

some extent, additional safety screens of structural steel were erected in the tunnels behind the traveling stage, and a spare one was built in each tunnel after the shield had moved about 300 ft., leaving one screen to be shifted ahead for the next 300 ft.

The original design of screens was fitted with a light air-lock large enough to take the whole gang of workmen, the forward door of which was shrouded by a curtain that came half way down the air-lock. The doors were hinged to open backward from the shields, because, if the tunnel was flooded for any depth above the bottom of the safety curtain, the pressure of the air between the screen and the bulkhead must necessarily be higher than the pressure between the screen and the shield, or the water would flood the space behind the screen. The curtain was made of $\frac{5}{16}$-in. plates stiffened on the rear by an I-beam, 12 in. deep and 35 lb. in weight, along the bottom edge, with additional stiffening Z-bars horizontally and vertically.

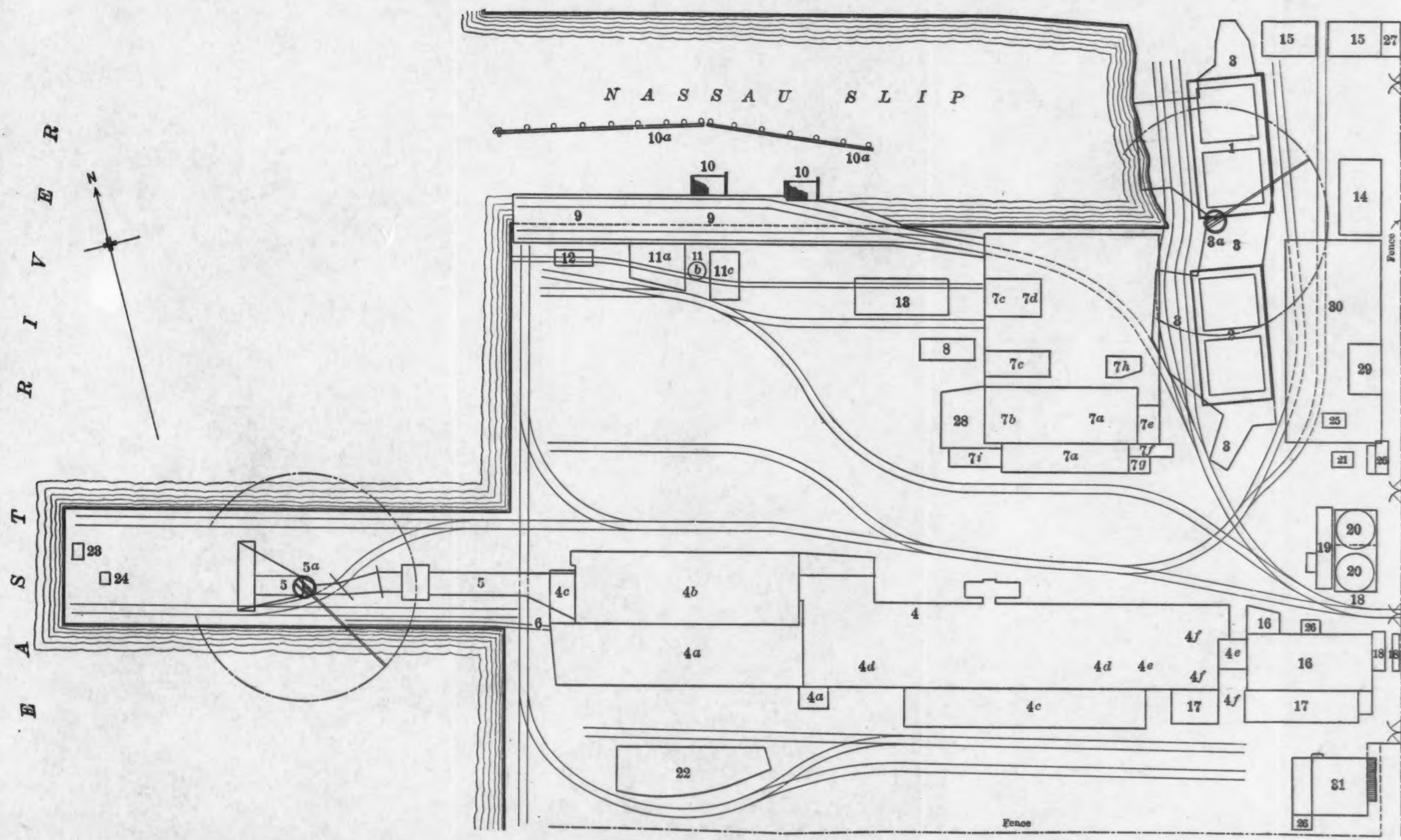
Adjustable segment plates stiffened by a heavy angle bar were drawn up into the circumferential caulking recess of the tunnel lining by eye-bolts suspended from the tunnel bolts, and at the same time the screen was held up by similar eye-bolts passing through heavy angle brackets on the screen. Flanged openings pierced the screen, for the passage of pipes, but it was found easier to depress the pipes under the screen than to cut them to dead lengths to fit the position of the screen.

Although the drawing shows the air-tight joint as having been made by a rubber gasket, the best results were obtained with lead caulking.

The latest type of screen, shown by Fig. 2, Plate IX, and on Plate XI, instead of being fitted with an air-lock, had a square opening, 2 ft. 3 in. by 3 ft. 3 in., the sill of the door being 5 ft. 2 in. above the bottom of the screen, which was set 1 ft. 2 in. above the axis of the tunnel. From the flying gangway a light platform led to this door on either side, the object being to dispense with diving under the curtain if the water rose above the bottom of the screen.

A flying gangway, Fig. 2, Plate IX, was provided throughout the length of the tunnel, supported by timber hangers from the tunnel lining. It connected with the traveling stage behind the shield by means of a runway, and dipped under the safety screens and connected with the staging at the air-tight bulkheads beside the man-lock.

This gave the men a dry means of escape while the water was



EAST RIVER
N
NASSAU SLIP
Fence
Fence
1
2
3
3a
4
4a
4b
4c
4d
4e
4f
5
5a
6
7a
7b
7c
7d
7e
7f
7g
7h
7i
8
9
10
10a
11
11a
11c
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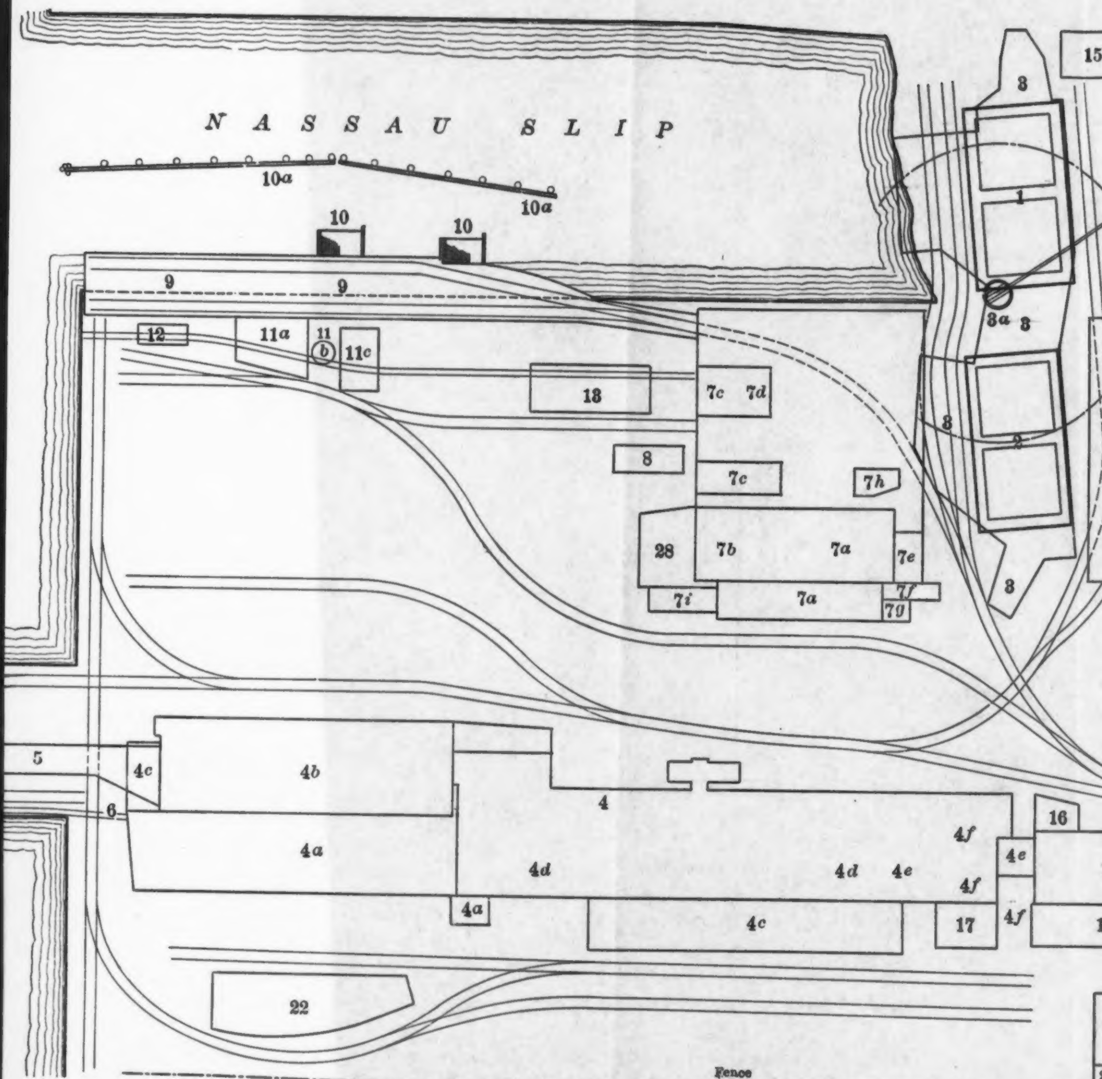
NASSAU SLIP
10a
10a
10
10
9
9
12
11a
11
b
11c
18
7c
7d
8
7c
7h
28
7b
7a
7e
7i
7a
7f
7g
15
8
1
8a
8
8
2
8
5
4c
4b
6
4
4a
4d
4d
4e
4f
4f
4e
4f
16
4a
4c
17
22
Fence

PLATE XV.
TRANS. AM. SOC. CIV. ENGRS.
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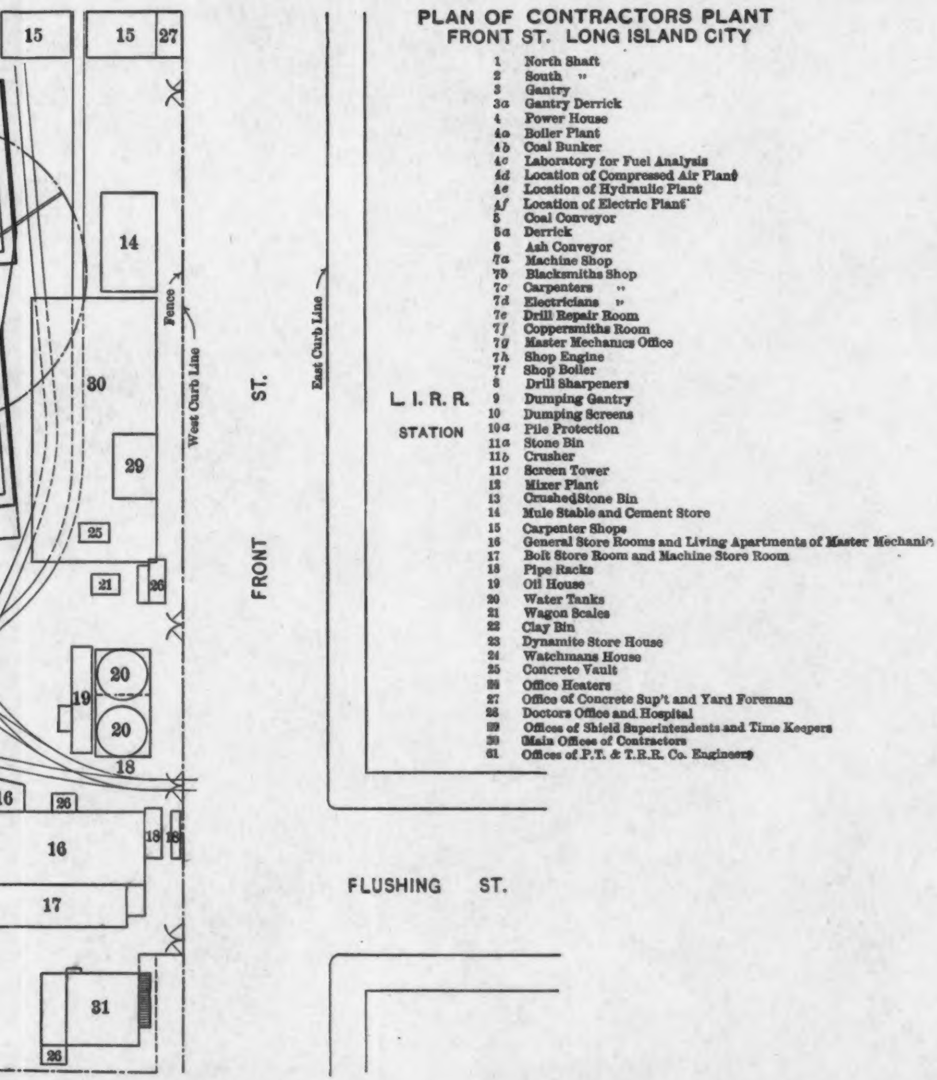
JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.



rising. No stairway communicated between the floor of the tunnels and this gangway, except near the air-locks, as in emergency it was easily reached by climbing up the flanges of the segments.

Air-locks and Bulkheads.—The concrete bulkheads, Fig. 1, Plate IX, and Plate XII, made strong enough to withstand an internal pressure of 50 lb. per sq. in., were built of concrete 10 ft. 6 in. thick. In this were placed two bottom muck locks, one emergency lock, one timber and rail lock, and one engineer's lock for carrying through the lines for surveying the tunnels. In addition, it was pierced by the various pipes and electric cables required for the work in duplicate.

The material air-locks were 20 ft. long and had a mean diameter of 7 ft.; the diameter of the emergency locks was the same, but they were 24 ft. long, as shown on Plate XII.

It was found during the progress of the work that the 24-ft. lock was bigger than was necessary for the number of men at work, and in the second series of bulkheads the 24-ft. lock was put in place of the right-hand or ingoing material lock. By this change it was possible to take long lengths of pipes, timber, and rails straight through on the cars without the expense of unloading them, passing them through the timber lock and reloading them inside the air-lock.

In the bulkheads, where the locks were already fixed, the incoming material locks were lengthened for the same purpose. The locks were made to stand an internal pressure of 50 lb., and that portion of them which extended into the tunnel under pressure from the outside was stiffened to take the same pressure on the outside.

In order to give them a better grip of the concrete bulkhead, and at the same time to take up the external pressure due to the bulkhead acting as a concealed arch, angle rings were riveted outside the locks. Doors giving a clear opening, 5 ft. high and 4 ft. wide, were hinged to swing inward toward the tunnel at each end of the air-locks. They were of the double-dished variety, of the Blackwall tunnel type.

In the emergency lock, brackets were bolted to the shell plates, on which were fixed wooden seats for the men. Bull's-eyes, 6 in. in diameter and 1¼ in. thick, were fitted in the ends of each lock. All three air-locks were fitted with 1½-in. man-valves for the inlet and outlet of air. In addition, the upper lock had a 1½-in. emergency cock which could be opened from the inside of the tunnel to bring back the lock; an additional 1½-in. exhaust valve was also fitted.

A clock and a pressure gauge were fixed in each air-lock for guiding the men as to the rate of decompression, and an automatic decompressing valve was also attached. The details of these decompressing valves will be found in a paper by the writer entitled "Caisson Disease and Its Prevention."*

For locking out materials, 3-in. cocks were fitted, but their diameter was ultimately increased to 4 in. In order to safeguard the workmen who used the muck locks for entering or leaving the tunnels, these 4-in. cocks had their counterpart inside the lock, so that the men could close them and operate the lock by means of the man-valves. The track was continued up to the well in which the lock door swung, and on the Manhattan side, this was bridged by two short lengths of independent rail which fitted into a recess on the door sills, and could be very quickly placed in position by the lock tender. On the Long Island side, two short rails were coupled together and hinged so that they could be swung up out of position to allow the door to open. Either method works well.

The pipe lock, which proved ultimately to be unnecessary, and expensive to operate, was 31 ft. long, of steel pipe, 21 in. inside diameter, fitted on the inside with a hinged door opening inward to the tunnel and seating on a rubber gasket against the flange of the pipe. On the outer end there was a box 2 ft. 10 in. square and 27 in. long with an opening 17½ in. square with a door opening inward.

Cross-Passage Locks.—Communication locks between tunnels were fitted at Long Island City to operate with the pressure either way (Plate XIII).

Blow-out Lines.—Two 6-in. water blow-out lines, and one 6-in. foul-air blow-out line passed along each tunnel. Branches were fitted at each bulkhead to take out any water collecting there, and at the shield a stuffing-box was bolted to the pipe in which was a telescopic pipe fixed rigidly to the traveling stage. From this a 6-in. flexible pipe dropped to the invert with a strainer on the end of it. This very quickly drew out any water that collected, and in the quicksand section took a great quantity of sand, which was blown along with the water into the sump at the foot of the shafts.

On account of the sand passing through the pipes, they were very quickly cut away, and at the bulkheads this was a serious matter, as

* *Transactions*, Am. Soc. C. E., Vol. LXV, p. 1.

PLATE XVI.
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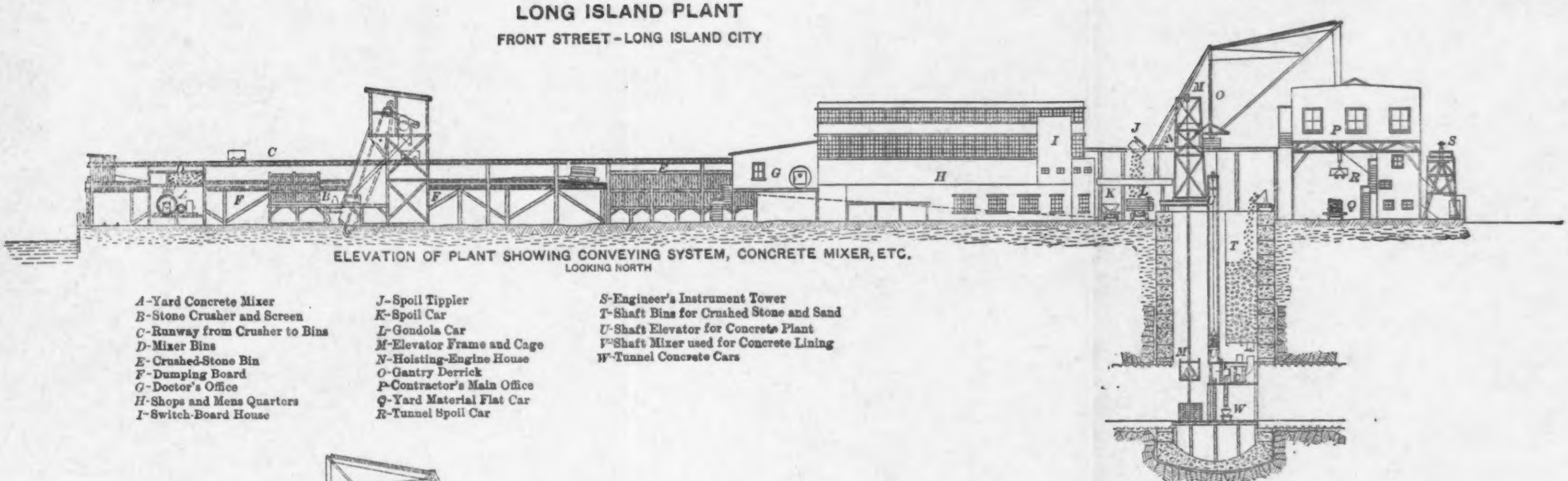
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

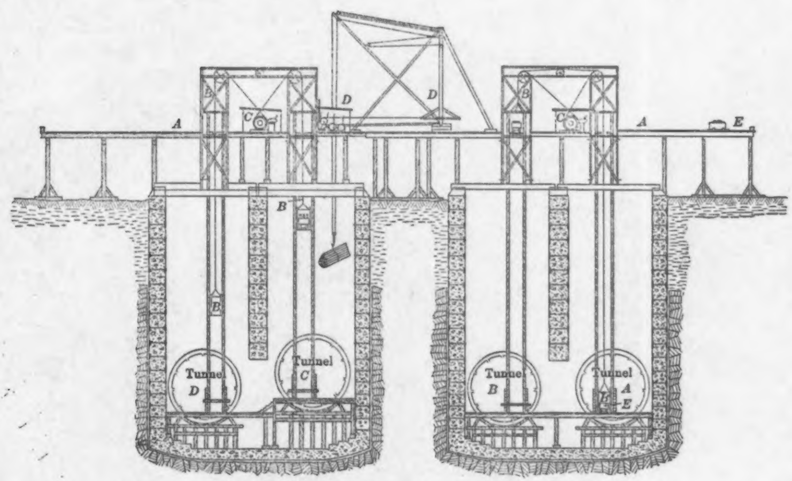
LONG ISLAND PLANT

FRONT STREET – LONG ISLAND CITY



ELEVATION OF PLANT SHOWING CONVEYING SYSTEM, CONCRETE MIXER, ETC.
LOOKING NORTH

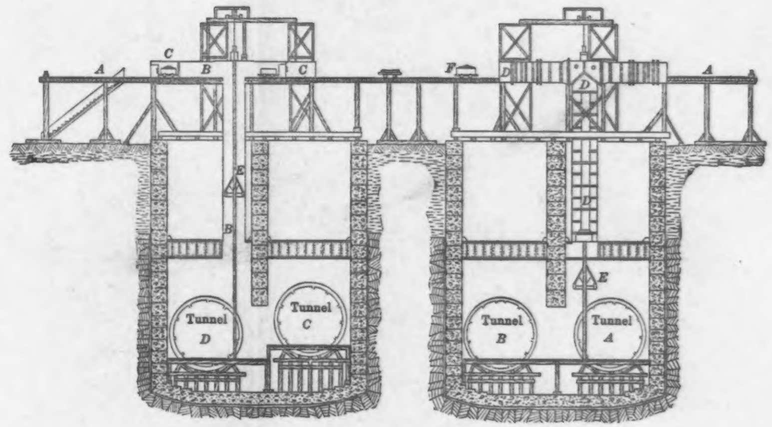
A-Yard Concrete Mixer
B-Stone Crusher and Screen
C-Runway from Crusher to Bins
D-Mixer Bins
E-Crushed-Stone Bin
F-Dumping Board
G-Doctor's Office
H-Shops and Mens Quarters
I-Switch-Board House
J-Spoil Tippler
K-Spoil Car
L-Gondola Car
M-Elevator Frame and Cage
N-Hoisting-Engine House
O-Gantry Derrick
P-Contractor's Main Office
Q-Yard Material Flat Car
R-Tunnel Spoil Car
S-Engineer's Instrument Tower
T-Shaft Bins for Crushed Stone and Sand
U-Shaft Elevator for Concrete Plant
V-Shaft Mixer used for Concrete Lining
W-Tunnel Concrete Cars



SOUTH SHAFT NORTH SHAFT

SECTIONAL ELEVATION THROUGH SHAFTS AND GANTRY
LOOKING WEST

A-Gantry Floor
B-Elevator Framing and Cages
C-Hoisting Engine Houses
D-Gantry Derrick and Hoisting Engine
E-Tunnel Spoil Car



SOUTH SHAFT NORTH SHAFT

SECTIONAL ELEVATION THROUGH SHAFTS AND GANTRY
LOOKING WEST

A-Gantry Floor
B-Sectional Elevation of T-Head Shaft and Locks
C-Locks
D-Outside Elevation of T-Head Shaft and Locks
E-Elevator Cages
F-Tunnel Spoil Car

there was no way to replace them. Advantage was taken of two 8-in. spare pipes which passed through the bulkhead near the floor level, and extra heavy 6-in. pipes were passed through these 8-in. pipes and flanged, and the annular space between caulked with lead. It was always possible to renew this extra-heavy internal pipe in case it was cut out by sand.

Many minor accidents occurred to workmen who passed close to the end of the blow-pipes when the strainer was off. Similar accidents took place at the big muck valves of the material air-locks. It was common for a man, with his coat over his arm, waiting for the lock to be sent back, to have it snatched off and sucked through the 4-in. valve into the air-lock.

Caisson Air-locks.—For sinking the caissons, Moran-Barr air-locks, leased from the John F. O'Rourke Company, were used. The upper door of this lock is in two parts and slides together, meeting in the center of the opening around a brass bushing on the cable. The sliding of the doors is accomplished by air cylinders, and the lower door is a simple hinged flat door opening inward toward the caisson by hand. These locks worked exceedingly well and rapidly. The maximum number of ½-cu. yd. skips taken out of one caisson fitted with two air-locks, but with only one crane at work, was 256 in 8 hours. When the caisson was just started, the pressure being about 10 lb., it was quite easy to open the upper sliding doors, although the pressure of the caisson was against them. On three occasions, the lock tenders, in their desire to hustle things, opened the upper sliding doors before the bottom door was properly closed, the result being that the skip of muck was violently shot up in the air. As this might have resulted in the loss of all the air in the caisson, with consequent flooding and drowning of the workmen, an interlocking gear was designed, consisting of a connecting link on the lever of the bottom door controlling a pin which prevented the opening of the upper sliding doors until the lower door was fully closed. This effectually prevented such accidents.

The general details of these air-locks have been illustrated so frequently that it is unnecessary to describe them here. They were mounted on an elliptical shaft divided with a partition to give room for ½-cu. yd. buckets to pass up and down freely, and on the other side of the partition a ladderway for the workmen was fixed. Two sets of shafting, with an air-lock on each, passed through the air-tight

floor, which consisted of steel girders at 5-ft. centers, 29 ft. long and 6 ft. deep, supporting ½-in. steel buckle-plates with a rise of 6 in.

So many accidents have occurred through fire, with wooden air-tight floors, that the contractors determined to go to the extra expense of the steel buckle-plates.

After the caissons were sunk and sealed, the air-tight floors were removed and the shields were built in position on wooden cradles. When they were built, a full set of tunnel air-locks was lowered beside each shield, and the air-tight floor was rebuilt above the shields, and these air-locks were hoisted up, and suspended underneath the floor, out of the way, as shown by Fig. 19.

After the shields had advanced 500 ft., the tunnel air-locks were lowered and built in position for the first bulkhead. This saved a heavy item for labor over what it would have cost to lower the air-locks in sections through the shaft air-locks, transport them along the tunnel, and build them in position.

When the air-tight floors were rebuilt, it was considered that the O'Rourke air-locks, hoisting ½-cu. yd. skips, would be inadequate for handling the excavation from two shields. It was decided, therefore, that tunnel muck cars should be used, and an elevator was installed in a vertical shaft which opened out into a T-headed air-lock, Fig. 19. The vertical shaft was built up of air-lock material which was needed later for tunnel bulkheads, with the addition of a steel plate about 3 ft. wide, which increased the diameter from 7 to 8 ft.

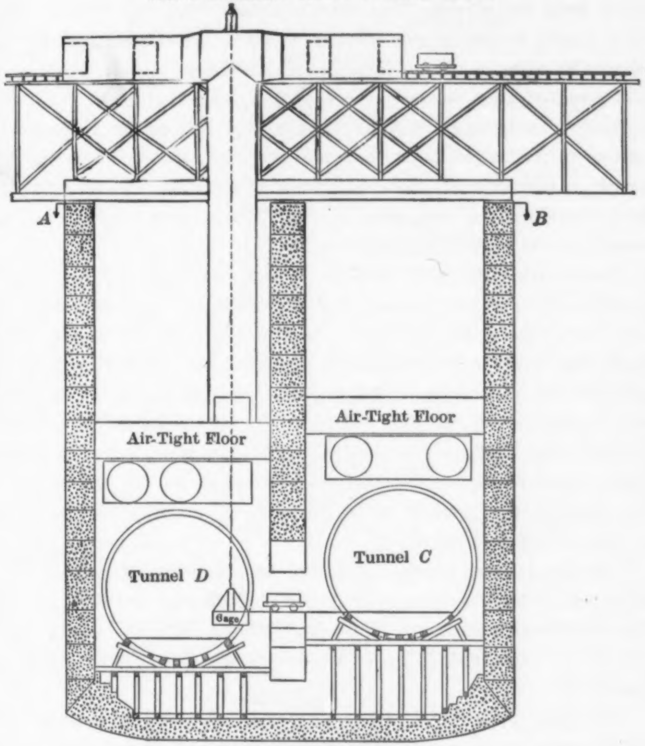
A special miter section crowned the 8-ft. vertical shaft, and, reducing to a diameter of 7 ft., branched out on either side into two standard horizontal air-locks, each 12 ft. long, giving enough space for one tunnel car at a time.

The cage, in the vertical shaft on timber guides, was designed to pass between two of the air-tight floor girders.

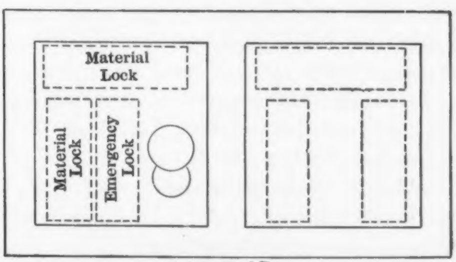
To one side of the vertical shaft, partitioned off from the space occupied by the cage, two vertical steel ladders were fitted to give the workmen access to the tunnels if the cage were out of order.

To give the workmen sufficient head room when the cage reached the top, a well was built underneath the cage track, so that they could stand down. The hoisting rope and the shackle on the over-winding gear of the cage passed up into a dome on top of the miter piece, fitted with a stuffing-box on top. As the shields were working in the

NO. 2 CAISSON WITH T-HEAD LOCK



SECTIONAL ELEVATION



PLAN AT *AB*

FIG. 19.

solid rock face at this time, one cage was able to take care of the muck from two shields. The vertical access shaft and T-headed locks were placed so that it was possible to build the regular pit-head gear above the caissons, with everything in readiness so that when the air was removed from between the first bulkhead and the air-tight floor, it required only an off Sunday to change over from the T-headed lock system to a straight hoist in atmospheric air with one cage for each tunnel. The air-tight floor was then removed at leisure, part of it being retained for use later as the bottom floor of the stone and sand bins for concreting operations.

For hoisting the spoil from the tunnels, one cage, Fig. 20, was provided for each tunnel, namely, four at Manhattan, four at Long Island City, and four at East Avenue. As the tunnels were in pairs in each shaft, the cages were operated in pairs off the same winch, so that when one cage was lowered the other one was raised. When the tunnels of a pair were at different levels, as at Long Island City and East Avenue, the difference in height was taken care of by having the drum divided into two sections of different diameters in the ratio of the heights, the greatest ratio being as 72 ft. is to 53 ft. for the *C* and *D* East Avenue cages.

The hoists were capable of lifting an unbalanced load of 2 700 lb. at a speed of 300 ft. per min.; 3 700 lb. at 200 ft.; and 5 000 lb. at 150 ft. The standard drums were 42 in. in diameter, and had a capacity for 140 ft. of wire cable $\frac{7}{8}$ in. in diameter, the drum being grooved to receive it.

The hoist was fitted with one band-brake and a solenoid-brake which went into operation when the electric circuit was broken from any cause. The hoists were built by the Lidgerwood Manufacturing Company, and the motors were supplied by the General Electric Company. They were of the fully-enclosed railroad type, wound for 220 volts, and could stand 100% overload for 1 min. without injurious sparking. They were operated by a controller with a reversing switch.

The cages, Fig. 20, were built of light 2-in. angle bars and were guided on 6-in. vertical timbers. If the cage dropped too quickly, either through accident or otherwise, toothed cams gripped the guides automatically and brought the cage to rest. King and Humble's patent safety over-winding catches were fitted overhead.

As an additional precaution, a wire rope was passed from one cage

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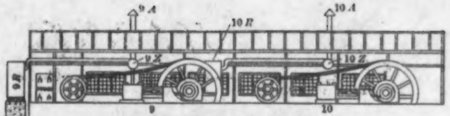
CONTRACTORS POWER P

FRONT ST., LONG ISLAND CITY.

NOTE:-

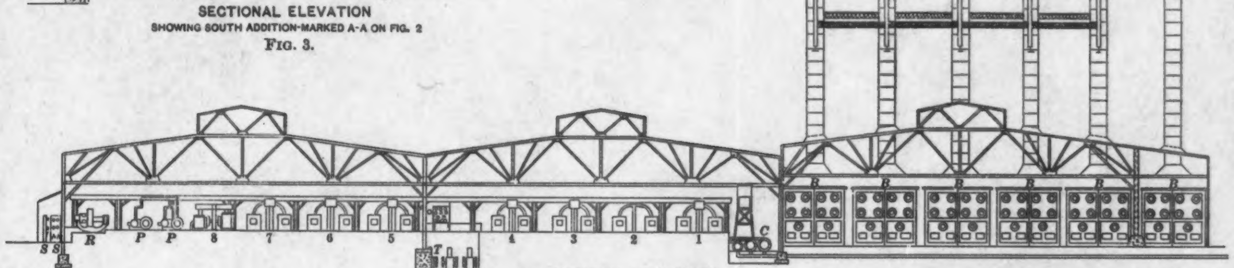
Numbers and letters always apply to the same object in all



SECTIONAL ELEVATION

SHOWING SOUTH ADDITION-MARKED A-A ON FIG. 2

FIG. 3.



SECTIONAL ELEVATION

ALONG NORTH SIDE OF COMPRESSORS AND BOILERS

FIG. 4.

FIG. 1.

1 *A* to 8 *A*.	Fresh Air intakes to Compressors.
1 *R*. 3 *R* to 7 *R*.	Low Pressure Air Receivers.
2 *R*.	Receiver for High Pressure Air.
K.	Receiver–after cooler
C 2.	Worthington Emergency Circulation Pumps.
C 3.	Electric Turbine " "
13.	Intakes " "
14.	City Water Connection to " "
15.	Coal Hopper and Scales House.
16.	Coal Elevator.
17.	Dynamite Store-house.
17 *a*.	" " watchmans shed.
18.	Coal Chutes for yard locomotives.

FIG. 2.

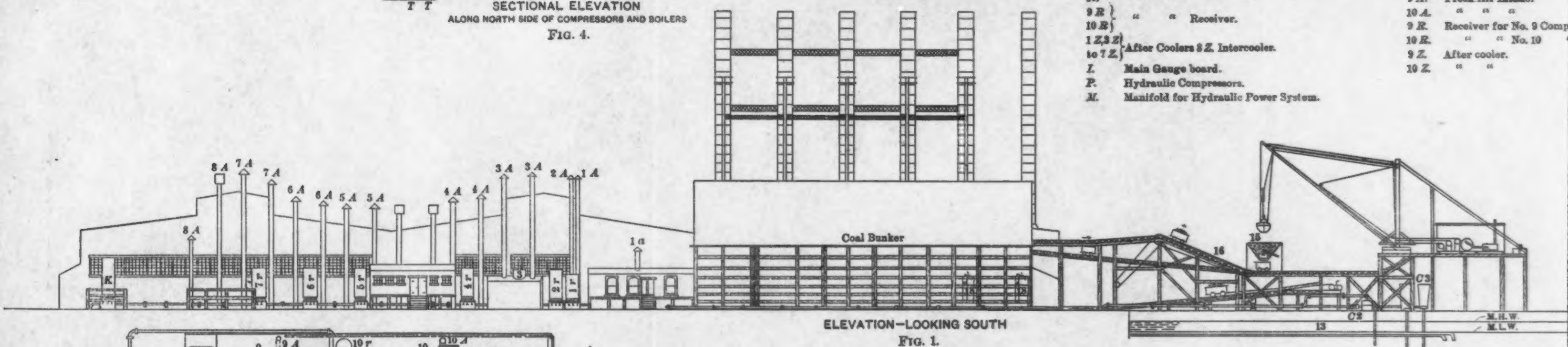
1.	Combination High and Low Pressure Compressor.
2.	High Pressure Compressor (changed to Low Pressure).
3 to 7.	Low " "
8.	High " "
9.	Low Pressure Motor driven Compressor.
10.	" " " " "
9 *R* 10 *R*	" " Receiver.
1 *Z*, 3 *Z* to 7 *Z*.	After Coolers 8 *Z*. Intercooler.
I.	Main Gauge board.
P.	Hydraulic Compressors.
M.	Manifold for Hydraulic Power System.

FIG. 2. continu

G.	Electric Generators.
R.	Rotary Converters.
S.	Switch Boards.
B.	Boilers.
D.	Forced Draft Fans.
F.	Feedwater Filters.
P.	" Pumps.
H.	" Heater.
C.	Cold water Circulation S
C 1.	" " "
C 2.	Cold water Emergency Worthington.
C 3.	Cold water Emergency Electric Turbine.
T.	Condensers.
E.	" Air Pumps.
W.	Hot Well.
X.	" " Pumps.
O.	Oil Fillers.

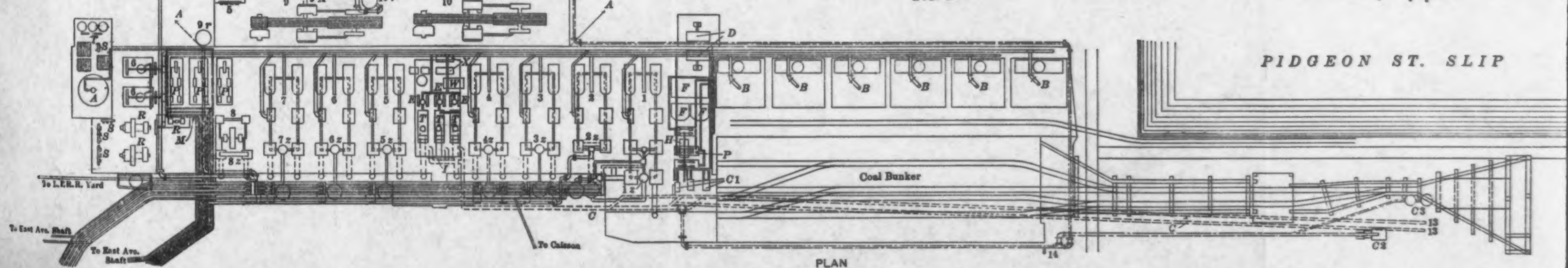
FIG. 3.

9.	Low Pressure Compress
10.	" " "
9 *A*.	Fresh Air Intake.
10 *A*.	" " "
9 *R*.	Receiver for No. 9 Comp
10 *R*.	" " No. 10
9 *Z*.	After cooler.
10 *Z*.	" "



ELEVATION—LOOKING SOUTH

FIG. 1.



PLAN

FIG. 2.

CO

NOTE:-

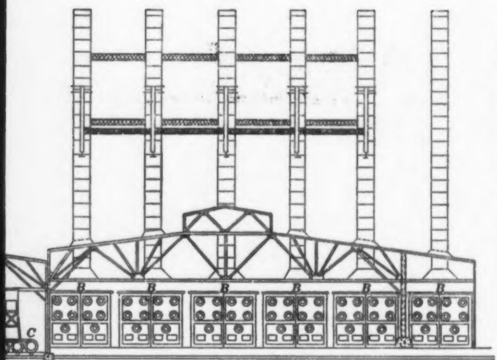
Numbers and

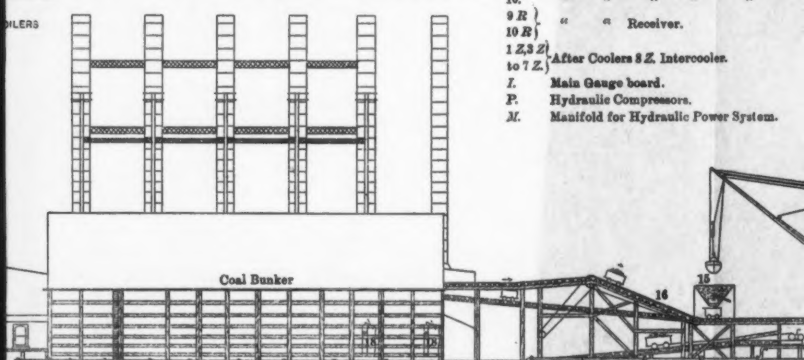
FIG. 1.

1 *A* to 8 *A*.	Fresh Air intakes to Compressors.
1 *R*. 3 *R* to 7 *R*.	Low Pressure Air Receivers.
2 *R*.	Receiver for High Pressure Air.
K.	Receiver–after cooler
C 2.	Worthington Emergency Circulation Pump
C 3.	Electric Turbine " "
13.	Intakes " "
14.	City Water Connection to " "
15.	Coal Hopper and Scales House.
16.	Coal Elevator.
17.	Dynamite Store-house.
17 *a*.	" " watchmans shed.
18.	Coal Chutes for yard locomotives.

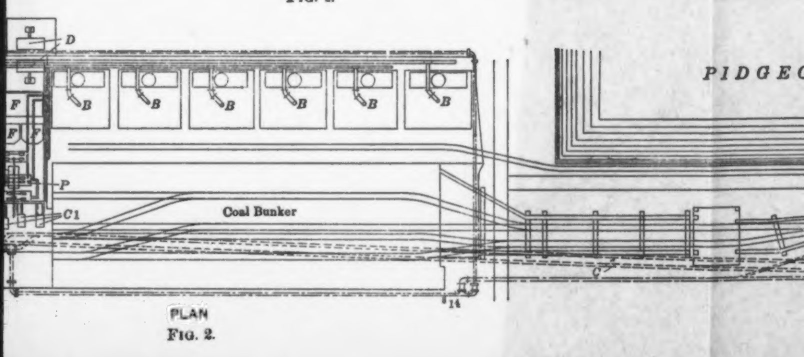
FIG. 2.

1.	Combination High and Low Pressure Comp
2.	High Pressure Compressor (changed to Lov
3 to 7.	Low " "
8.	High " "
9.	Low Pressure Motor driven Compressor.
10.	" " " " "
9 *R* 10 *R*	" " Receiver.
1 *Z*, 3 *Z* to 7 *Z*.	After Coolers 8 *Z*. Intercooler.
I.	Main Gauge board.
P.	Hydraulic Compressors.
M.	Manifold for Hydraulic Power System.





ELEVATION—LOOKING SOUTH
FIG. 1.



PLAN
FIG. 2.

PLATE XVII.
TRANS. AM. SOC. CIV. ENGRS.
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PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

CONTRACTORS POWER PLANT

FRONT ST., LONG ISLAND CITY.

nbers and letters always apply to the same object in all figures on this sheet.

s.
ation Pumps.
"
"
"
s shed.
s.
ssure Compressor.
ged to Low Pressure).
pressor.
"
ystem.

FIG. 2. continued.

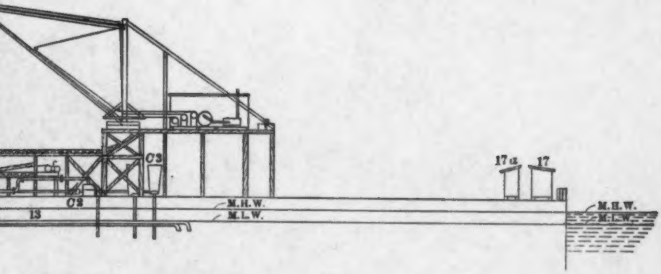
G.	Electric Generators.
R.	Rotary Converters.
S.	Switch Boards.
B.	Boilers.
D.	Forced Draft Fans.
F.	Feedwater Filters.
P.	" Pumps.
H.	" Heater.
C.	Cold water Circulation System (in part).
C 1.	" " " Pumps.
C 2.	Cold water Emergency Circulation Pumps. Worthington.
C 3.	Cold water Emergency Circulation Pumps. Electric Turbine.
T.	Condensers.
E.	" Air Pumps.
W.	Hot Well.
X.	" " Pumps.
O.	Oil Filters.

FIG. 3.

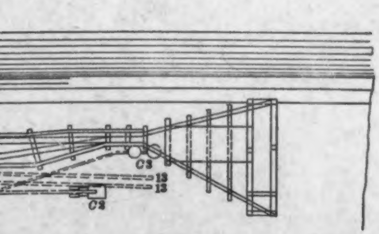
9.	Low Pressure Compressors.
10.	" " "
9 *A.*	Fresh Air Intake.
10 *A.*	" " "
9 *R.*	Receiver for No. 9 Compressor.
10 *R.*	" " No. 10 "
9 *Z.*	After cooler.
10 *Z.*	" "

FIG. 4.

C 1.	Circulation Pumps.
C.	" Suction Pipe Line.
B.	Boilers



DGEON ST. SLIP



to the other over the pit-head sheaves, which were double-grooved; and, midway between the two pit-heads, overhead, it passed four times round a drum fitted with a band-brake controlled by a lever in the hoisting-engine house. In the event of the hoisting rope breaking while the cage was being elevated, the loaded cage on falling pulled up the

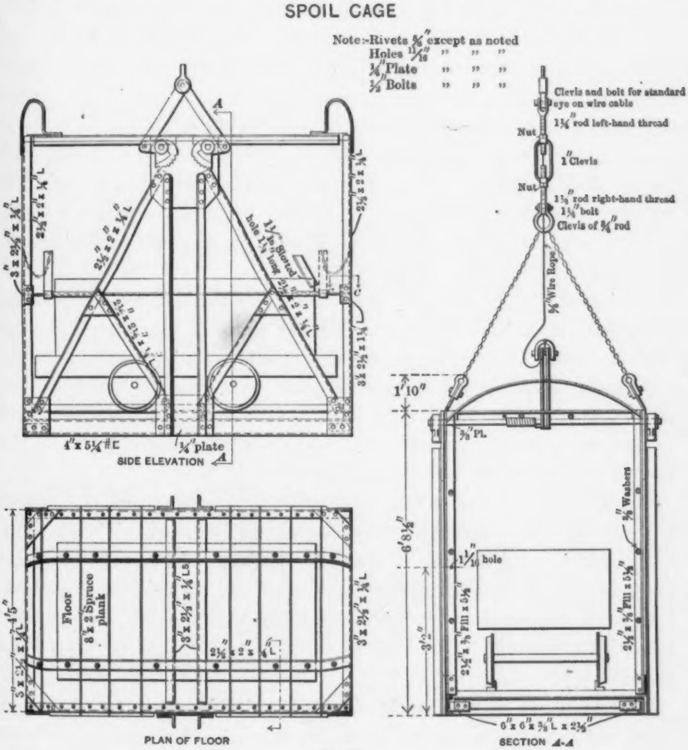


FIG. 20.

empty cage by means of the additional rope. When this occurred, the operator put his foot on the lever controlling the band-brake of the free drum, and brought the cages to rest without accident, this being necessary only if the automatic grips failed to act.

To prevent anything falling down the pit, a light wooden cover rested on the upper floor and slid on the guides. This was lifted clear

by the rising cage. On the upper level, the cage rested on tumblers, which closed automatically when the cage passed through them. At the bottom, an automatic gate lifted when the cage came down, and fell into position when the cage rose. These were apt to get out of order, and the most usual method for protecting the bottom was with a light piece of chain hung across the opening. The cars were kept in place in the cage by two swing-bars. The loaded muck cars, on reaching the surface, were pulled out by hand and run into a tippler where they upset automatically and dumped into muck bins. The tippler was built very strongly of 56-lb. rail, and was designed so that, with the loaded car, the center of gravity was such that the car and tippler turned upside down, and, when the car emptied, the center of gravity was such that the car came back to its normal position. If the muck was sticky, it was necessary to catch the tippler upside down on its swing.

Pumping Plant.—For the compressed air tunnels, no pumps were necessary in the air chamber, as the air pressure blew the water out through pipes to the sump. It was possible, under special circumstances, by allowing air to leak into the pipe from the chamber, for the water to be delivered right up into the river without the use of pumps, but generally it was more reliable to blow the water from the tunnel into the shafts and pump from there.

At the foot of each shaft, as a stand-by in the event of flooding, one special 6-in. vertical turbine pump was installed. These pumps were capable of delivering 60 000 gal. per hour. Three of them were built by the Worthington Company, and two by R. D. Wood and Company, the motors, of 50-h.p. each, being made by the Northern Electric Company. The motors were enclosed in a water-tight chamber.

For ordinary service work, the most suitable pump for the rough work and large volumes of water proved to be the Cameron No. 12, with 18-in. steam and 12-in. water cylinders, and a 20-in. stroke. These were the main stand-bys on the Manhattan side, while on the Long Island side, Blake duplex pumps, with 14-in. steam and 12-in. water cylinders, and a 10-in. stroke, were installed.

At the East Avenue site of the works, a great number of pumps were necessary in the headings and break-ups, and outside the air-tight bulkheads at the lower end of this section. The No. 9 Cameron pump

PLATE XVIII.
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PLAN OF SECOND-FLOOR GANTRY

FIG.1

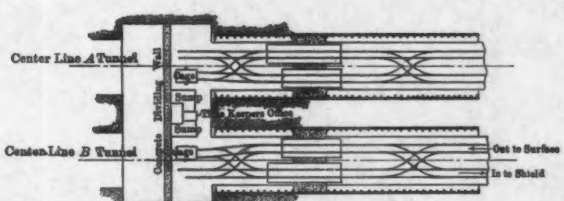


FIG.3
PLAN AT BOTTOM OF *A* AND *B* SHAFT SHOWING TRACK LAYOUT. CAGES AND MATERIAL LOCKS IN FIRST BULKHEAD

THIRD-FLOOR GANTRY

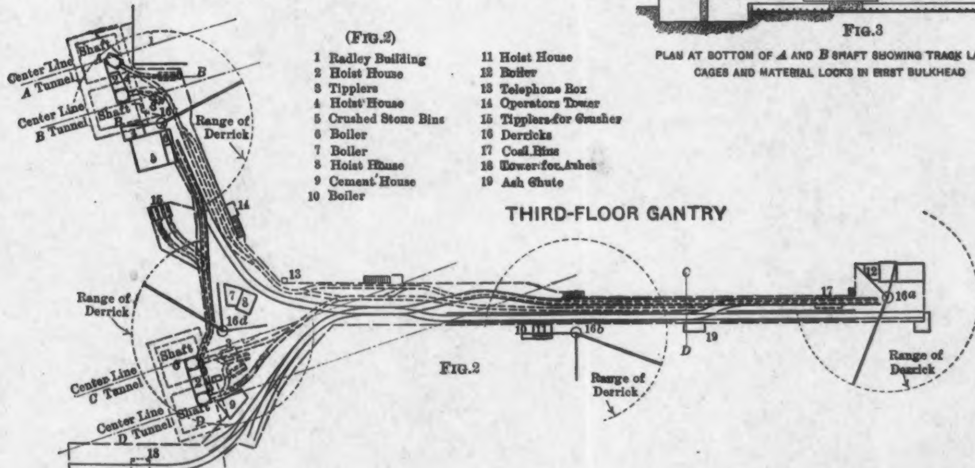


FIG.2

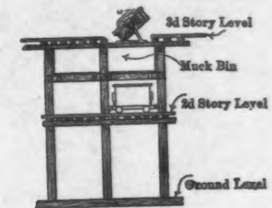


FIG.6
SECTION *AB* FIG. 2

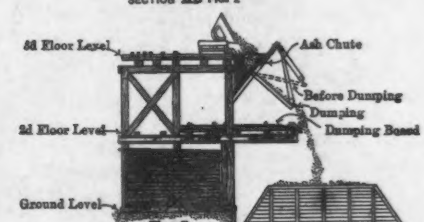


FIG.7
SECTION *CD* FIG. 2

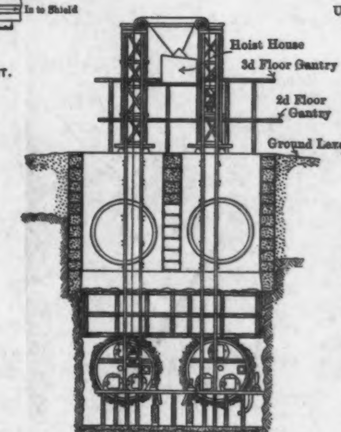


FIG.4
SECTIONAL ELEVATION OF *AB* SHAFT LOOKING EAST

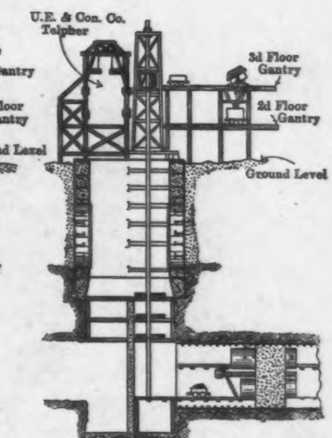


FIG.5
SECTIONAL ELEVATION OF TUNNEL *B* AND SHAFT LOOKING NORTH

was generally adopted, although smaller sizes were used at various points. These pumps take up so little room that they can stand at the side of the headings without interfering with the passage of cars.

As the operation of pumps by air pressure is very expensive, the contractors converted several of their Worthington duplex pumps (with two water cylinders 8½ in. in diameter and 7-in. stroke), and drove them electrically, with a 10-h.p. motor gearing to a crank shaft at 40 rev. per min. These were very useful at East Avenue, and four of them have been at work ever since the air pressure was taken off, in the permanent pump chambers under the river. The efficiency was found to be 55%, including about 20% loss in the transmission and the motor, 19% loss in the gearing and friction, and about 6% loss by leakage.

Spoil Removal.—At the East Avenue site, after the muck was dumped into the bin, it was allowed to pass into Long Island Railroad cars and was taken out on Long Island. At Long Island City, a small part of it was handled in the same way, while the greater portion was dumped from the muck bins into 4-cu. yd. side-dumping steel cars. These were transported by a small locomotive and pulled up an incline by a Lidgerwood winch to a cantilever staging overhanging the water at the dock, where they were dumped to deck scows provided by the Railroad Company.

At times when shortage of railroad cars and scows occurred simultaneously, it became necessary, in order to keep the tunnels going, to dump the muck in the yard and reload it when scows were available.

On the Manhattan side, the muck was dumped into 4-cu. yd. steel side-dumping cars and run by electric locomotives to an overhanging cantilever staging, as at Long Island City. At this site, if scows were not available there was no alternative but to store the muck along the staging or in the tunnel. Even the muck bins at this site were too small to take care of such material.

For unloading, storing, and rehandling the cast-iron tunnel segments, eight locomotive cranes were provided. These were built by Wilson, of Liverpool. They were of the usual type, with 40-ft. booms, capable of handling 5 tons at 16 ft. radius on a 7-ft. gauge, and 1¼ tons at 35 ft. radius. They have two steam cylinders 7½ in. in diameter and a 10-in. stroke, and a drum 18 in. in diameter and 32 in. long. They can run on either 4 ft. 8½-in. or 7-ft. gauge. The gauge of the

tracks on the dock was 7 ft., and a track of 4 ft. 8½-in. gauge ran down the center. This permitted the cranes, when taking a heavy lift, to have the benefit of the wider gauge; when they were running about the yard, handling light material, they stood on the 4 ft. 8½-in. gauge. One of these cranes was of 10 tons capacity, with steam cylinders 9 in. in diameter and a 10-in. stroke, running on two gauges, and capable of lifting 4 tons at 32 ft. radius, and 10 tons at 16 ft. radius.

Two cranes were fitted with a split drum for handling a two-line clam-shell, and were used for unloading crushed stone on the Long Island side. In addition to these cranes, numerous steam derricks were erected at different points.

Stone Crushers.—At each of the three sites, a No. 5, Style *K*, Gates gyratory crusher, was erected. The stone crusher was set on the ground level, the crushed stone being elevated to the screens by bucket elevators about 57 ft. high. These were 12 ft. long, 40 in. in diameter, with outside dust jackets. The refusals ran through a wooden shoot to the crusher, and the screened material went to the storage bin. The crushers were driven by a Bullock motor of 40 h.p., 220 volts, and 600 rev. per min.

The screen was divided into two sections, the first section, 60 in. long, punched with ¾-in. holes, and the second section, 84 in. long, with 1¾-in. holes. The outside dust jacket was 54 in. long, with ⅜-in. holes. They worked very well, but, for economical crushing, it would have been better to have had larger sizes, on account of the amount of sledging necessary before the stone could be passed through the crusher.

As the shields were passing through good stone at a time when little crushed stone was required for concrete, a large quantity was crushed and stored on leased land not far from the Long Island City site. Later, this was reloaded for concreting operations.

Concrete Mixers.—In the early stages of concreting the caissons and for other work, a small No. 2 Ransome concrete mixer was fixed at each site. No very elaborate arrangement was made for storage bins, as these machines were placed on the surface.

When concreting operations became possible in the tunnels, one No. 3 Ransome concrete mixer, driven by a 30-h.p. motor, was erected for each pair of tunnels. One of these was fixed in each of the Long

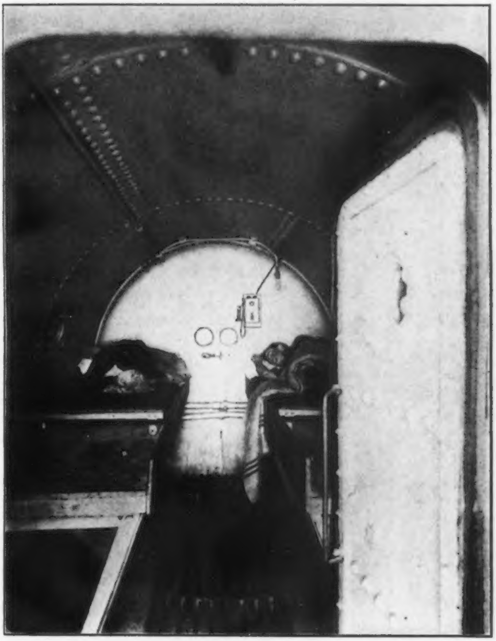


FIG. 1.—INTERIOR OF MEDICAL AIR-LOCK.

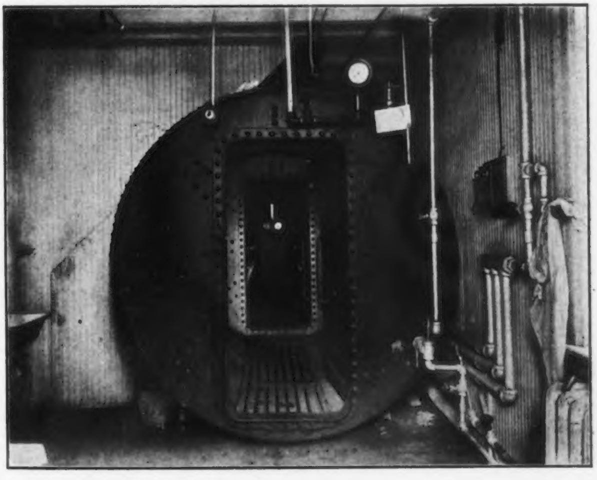


FIG. 2.—MEDICAL AIR-LOCK.

Island shafts, and also at the East Avenue shaft, while, on the Manhattan side, the 1-cu. yd. Smith concrete mixing plants of the United Engineering Company, including storage bins erected in the shafts, were purchased and used without alteration (Plate XX).

The mixers were placed high enough above the bottom of the shafts to discharge into the concrete cars, and bins of large capacity were built above them, up to the ground surface.

On the Long Island side, the air-tight floor was used for the bottom of the bins, and the girders from the other part of the floor were placed vertically, at 6-ft. centers, and reinforced concrete side-walls were built between them; at East Avenue the bins were made of timber. The concrete was discharged into 24-cu. yd. steel side-dumping cars, hauled by electric traction along the floor of the completed concrete lining, then hauled to an upper staging by an air-winch and incline, and distributed by mules and dumped where required. This staging was of timber, supported by byats, held on the cross-flanges of the tunnel lining. They were made in such lengths that the arch concrete could be put in without cutting the main byat, and the extra length required to reach the flanges was obtained by an extension piece on each end.

The concrete forms were entirely of timber coated with creosote. The only special feature was the method of holding up the laggings for the arch. This was done with angle bars curved to suit the arch and held by eye-bolts to the circumferential bolts of the tunnel lining. This detail is described more fully in another paper.

Pug Mills.—In order to prevent air leakage around the tail of the shield and between poling boards, it was necessary to have plastic clay. This was difficult to obtain, as the clay delivered on deck scows was usually in hard lumps. To soften it, two pug mills, made by C. B. Raymond and Company, were purchased, one for each side of the river. They were 9 ft. long and 30 in. in diameter, and consisted of a trough of ¼-in. steel in which a 4-in. shaft rotated 36 chilled pugging knives.

This was driven through gearing by a General Electric Company's 20-h.p. motor. Their capacity was guaranteed to be from 50 to 75 cu. yd. in 10 hours of continuous operation and feeding. These were very useful in the early part of the work, but, after a regular supply of soft Haverstraw clay was available, they were not used so often.

Dredging Plant.—In order to take care of the clay blanketing operations, a small dump-scow was purchased on which was mounted the

10-ton Wilson locomotive crane with a 2-yd. digger, Fig 21. This was found very useful for digging clay stored in the slips at Long Island, for taking care of "blows," but, as the War Department limited the width of clay blankets in the river, a large dredge was necessary for re-dredging the clay blanket and depositing it ahead of the tunnels. As the prices quoted for doing this intermittent work were high, it was a paying proposition for the contractors to buy a dredge and handle this work themselves. Therefore, they purchased a clam-shell dredge 94 ft. long, 30 ft. wide and 8 ft. deep, with main engines of two cylinders 14 in. in diameter and an 18-in. stroke, driving two pinions meshing with the main 8-ft. gears. Frictions, 7 ft. 6 in. in diameter,

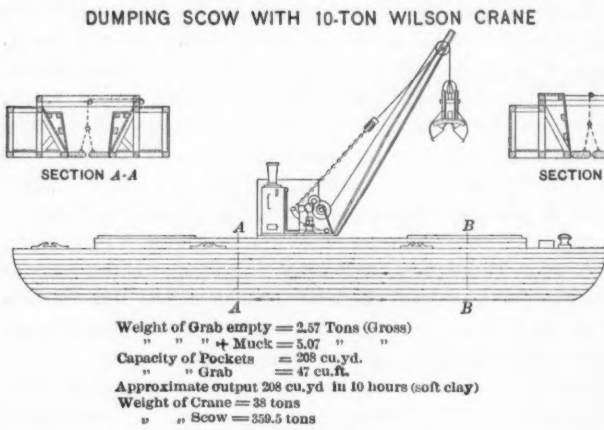
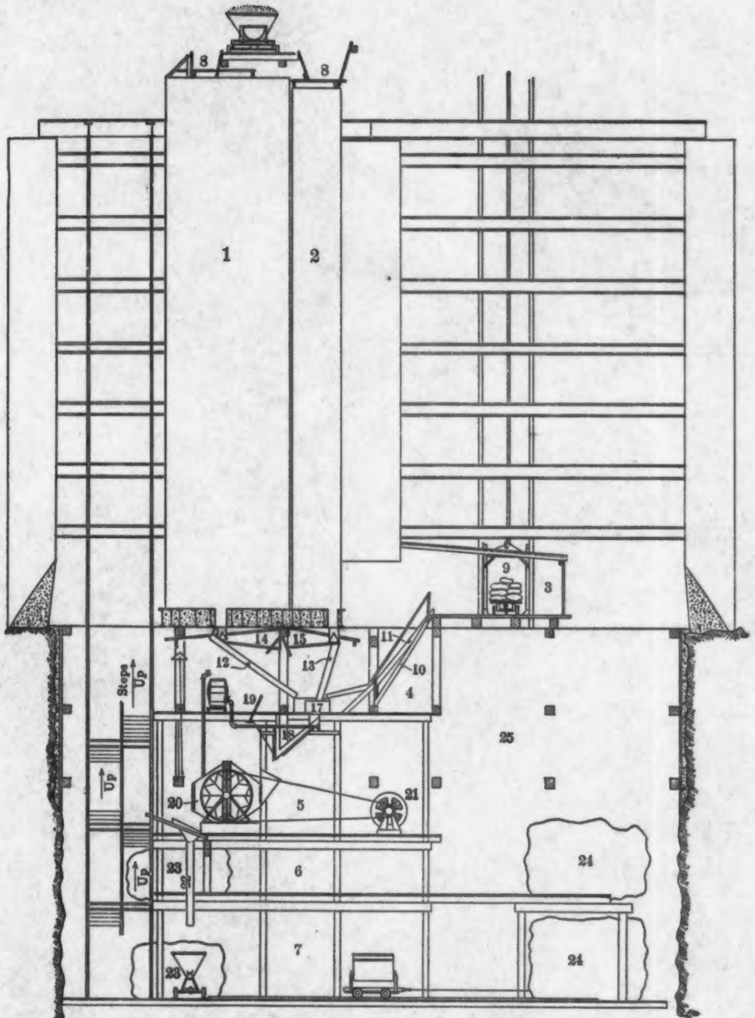


FIG. 21.

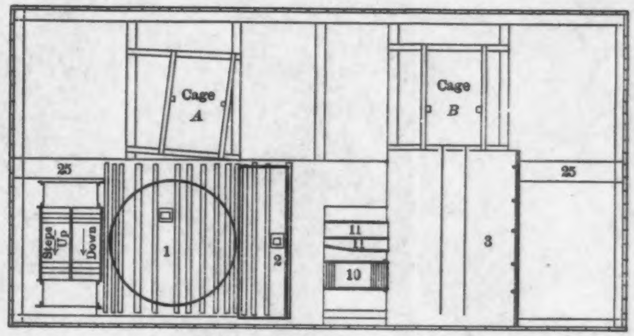
engaged in the main gears and drove two drums 2 ft. in diameter. The clam-shell bucket had a capacity of 4 cu. yd. when digging in heavy material, and 5 cu. yd. in lighter material. The weight of the 4-cu. yd. bucket loaded was 26 700 lb. Steam was supplied by a locomotive-type boiler, 5 ft. in diameter and 20 ft. long, with a grate area of 27 sq. ft., and a working pressure of 100 lb. This supplied enough steam to make a complete cycle of operations in 40 ft. of water in 40 seconds.

At the forward end, a mooring and spud-hoisting gear was fixed, driven by a steam engine having two 8-in. cylinders 9½ in. long. This geared into a countershaft which drove two anchor-rope drums, 3 ft. in

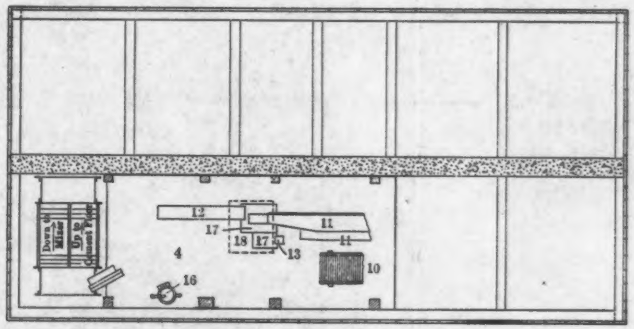
SKETCH OF CONCRETING ARRANGEM



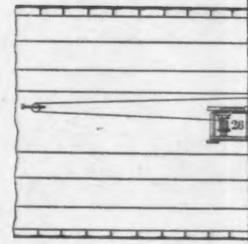
SECTION, CONCRETE MIXER. *A-B* TUNNELS



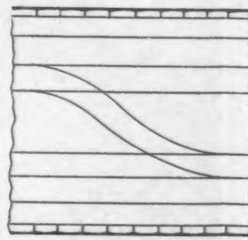
PLAN, CEMENT AND BIN FLOOR.



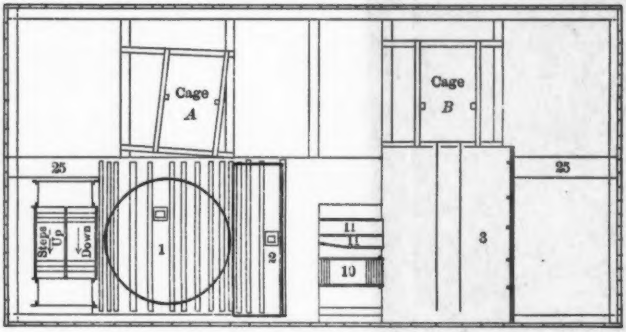
PLAN, HOPPER FLOOR.



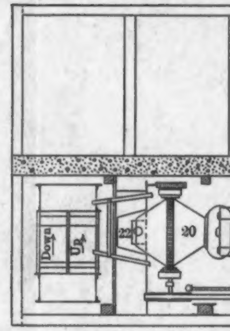
PLAN AT ELEVATIO

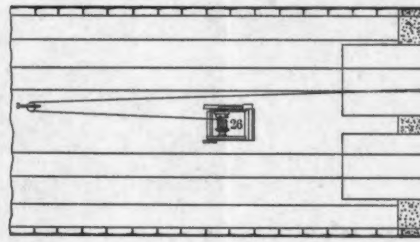


SKETCH OF CONCRETING ARRANGEMENTS, MA

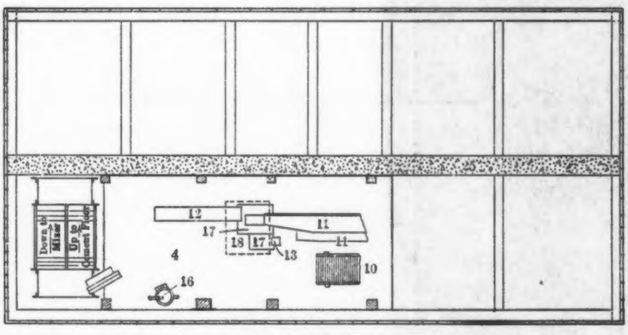


PLAN, CEMENT AND BIN FLOOR.





PLAN AT ELEVATION OF FLOOR OF TUNN



PLAN, HOPPER FLOOR.

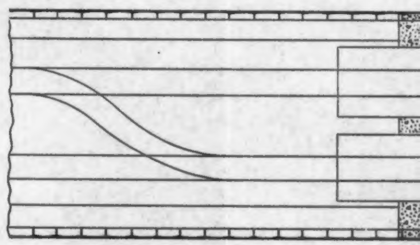
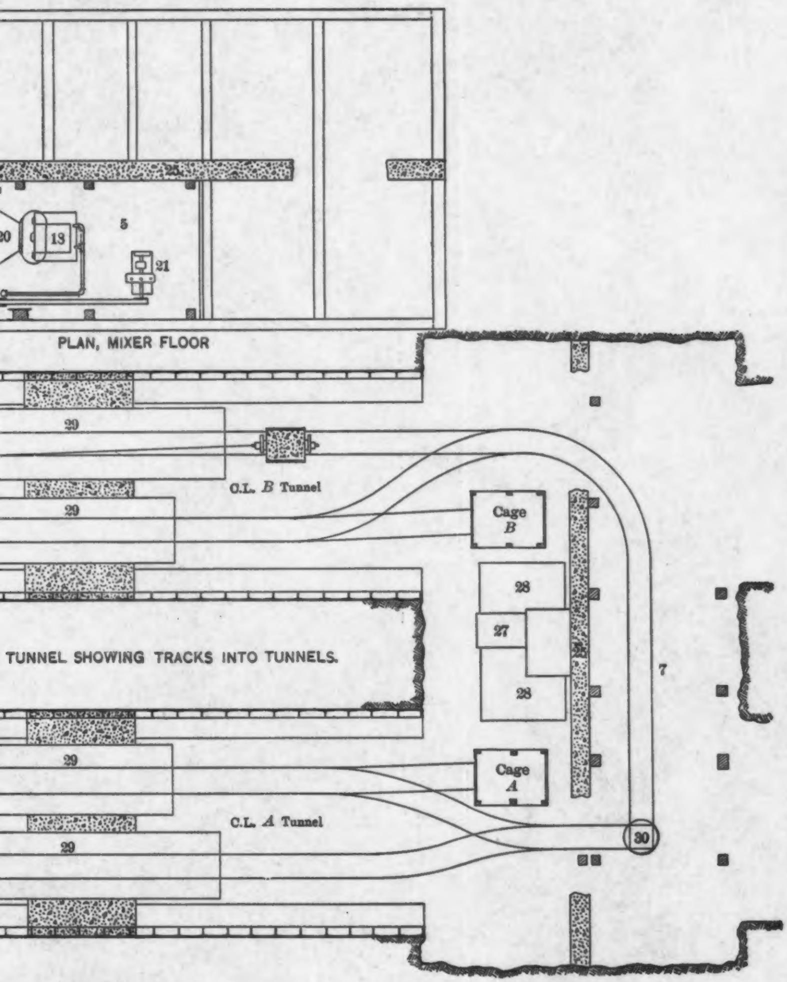


PLATE XX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1160.
JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

MANHATTAN.



1. Stone Bin.
2. Sand Bin.
3. Cement Storage Platform. .
4. Hopper Floor.
5. Mixer Floor.
6. Old Concrete Platform used at start, for Cars.
7. Floor for loading Cars.
8. Grating over Bins.
9. Cage on Line *B*.
10. Steps from Cement Floor to Hopper Floor.
11. Cement Chute.
12. Stone Chute.
13. Sand Chute.
14. Lever to open Stone Bin.
15. Lever to open Sand Bin.
16. Water Barrel.
17. Hopper Box.
18. Hopper.
19. Lever to open Hopper.
20. Smith Mixer.
21. Motor for driving Mixer.
22. Concrete Chute to Cars.
23. Holes cut in Division Wall for *A*.
24. Holes cut in Division Wall for *B*.
25. Concrete Division Wall.
26. Compressed Air Engine for hauling Concrete.
27. Timekeepers Office.
28. Sump.
29. Material Locks.
30. Turntable.

diameter, driven by 4 ft. 6-in. frictions, and two spud-hoisting drums, 2 ft. in diameter, driven by 3 ft. 6-in. frictions.

At the stern were fixed two engines, each with four single-acting cylinders, 6 by 10 in., working by a single crank directly on a worm which drove two drums 3 ft. in diameter for each winch. Five anchors, 2 500 lb. in weight, were used, and were attached by 1-in. steel ropes.

On the Manhattan side, this plant had to work in 48 ft. of water in a current varying in either direction up to 4½ miles per hour. The maximum output was 1 580 cu. yd. in a day of 10 hours.

The tugboat *Columbia* was purchased for handling the dredge and scows. Its dimensions were: 87 ft. long, 20 ft. wide, and 9 ft. deep, the gross tonnage was 96 tons. A boiler, 14 ft. long and 8 ft. 6 in. in diameter, supplied steam at 50 lb. pressure to a single-cylinder engine, 26 in. in diameter and 26-in. stroke, exhausting into a surface condenser.

Three scows were also purchased, namely, one 115 ft. in length, 32 ft. wide, and 12 ft. 10 in. deep, with six pockets, with a total capacity of 654 cu. yd., and two scows each 112 ft. long, 31 ft. 6 in. wide, and 12 ft. deep, with six pockets, with a total capacity of 588 cu. yd.

For marking off the position of the clay blankets, in accordance with the War Department's regulations, two hulks were purchased, to act as stake boats, and were moored in the river over the edge of the blanket, with large notice boards, giving particulars of the width and depth of the channel.

The foregoing is a summary of the general plant used on the East River tunnels. Plate XIV shows the general arrangement of the plant at the East Avenue site. One medical air-lock, Plate XIX, illustrated in the writer's paper entitled "Caisson Disease and Its Prevention,"* was used at this site while compressed air work was under way, and was later shifted to Long Island City. Men's locker rooms were built near the shaft, and the plan gives a good idea of the methods of handling the materials. The powder magazine was placed at the center of the block, as far from the general public as possible. A small workshop for repairs contained the following tools:

One Sibley and Ware drilling machine with a table 16 in. in diameter and a 20-in. feed,

One Sagar saw bench,

**Transactions*, Am. Soc. C. E., Vol. LXV, p. 1.

One 16-in. jointer and counter, with 16-in. knives,
One Ajax drill sharpener for 13 ft. 6-in. drills,
Four forges.

The Long Island City site is shown on Plates XV, XVI, and XVII, and has already been fairly well described, but this plan gives a good idea of the general working arrangements, showing how the materials and the spoil were handled. Two medical air-locks, Plate XIX, were erected, along with a doctor's office at the west end of the men's dressing-rooms. The powder magazine was placed at the end of the dock. An extensive workshop was provided, including the following tools:

One Sibley and Ware drilling machine, back-gear, feed, 20 in., table 16 in. in diameter,
One Fosdeck National drilling machine, 24-in. arm, drilling a 2-in. hole,
One Powis and Bale gap lathe, 18 and 36 in., and 8 ft. between centers,
One Harrington gap lathe, 28 and 48 in., compound rest, geared face-plate, 20-ft. bed, length between centers, 8 and 15 ft.,
One 24-in. Fitchburg lathe, 12-ft. bed,
One Saunders pipe machine, No. 7, complete,
Two Acme bolt-cutting machines, No. 2, complete,
One Jarecki pipe-cutting machine, No. 11, 1 to 6 in., also for bolts ½ to 2 in.,
One Williams and White double special punching and shearing machine, to shear 1-in. plate 6 ft. long, to punch 1½-in. hole in 1-in. plate,
One Bell standard guide steam hammer, with anvils and dies, 5 by 18-in. cylinder, 3 ft. 11 in. by 2 ft. 6 in. bed, height 8 ft. 2 in., anvil weight, 2 200 lb.,
One Sagar saw bench,
One band saw, No. L, wheel, 3 ft. in diameter, 500 rev. per min.,
One heavy swing saw, 30 in.,
One wood planer, 15-in. blades, 6 in. deep,
One Hoyt, No. 22, 30 by 6-in. planer and moulder, with divided rolls,
One Ajax drill sharpener, complete, with drills, dies, and dollies.

PLATE XXI.
TRANS. AM. SOC. CIV. ENGRS.
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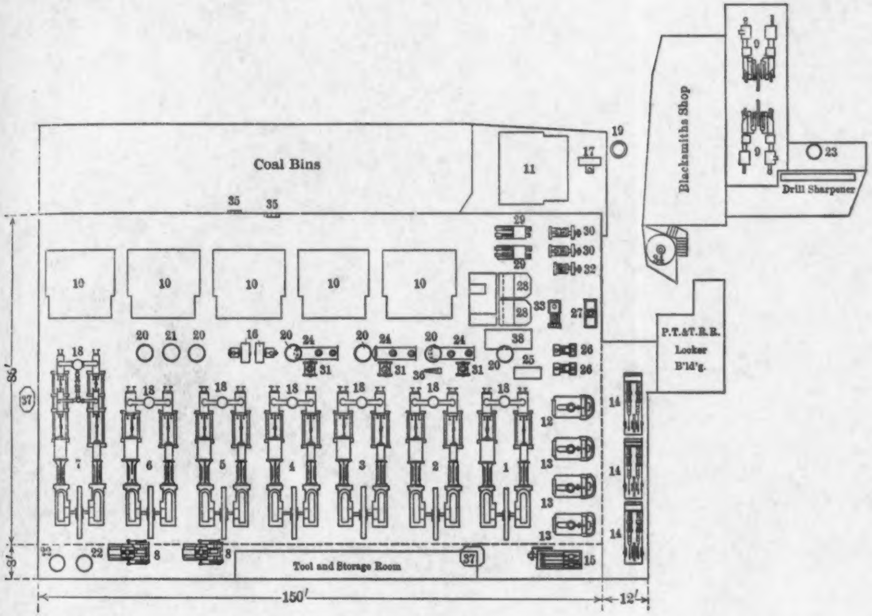
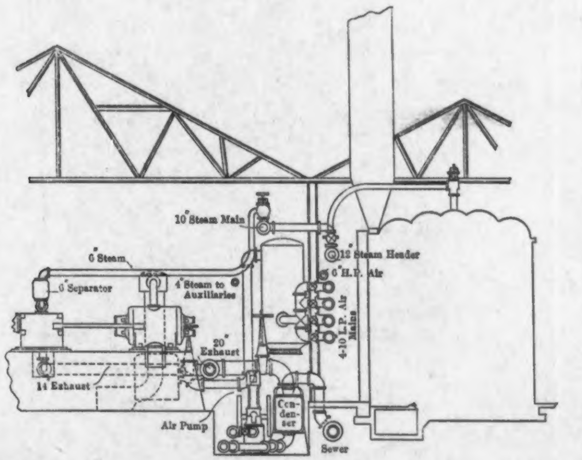
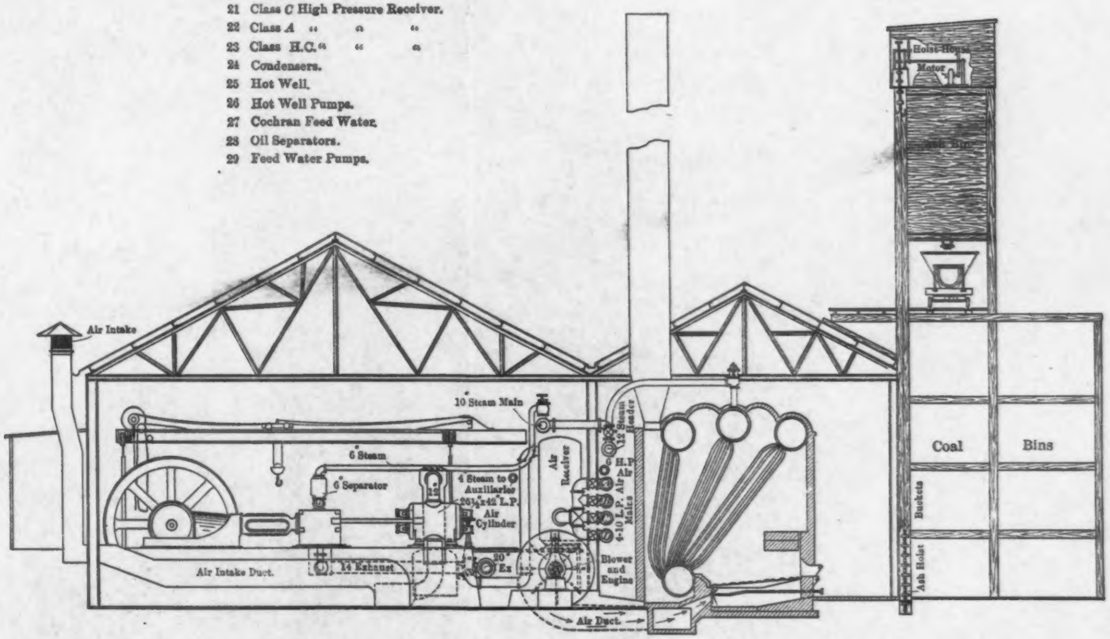
JAPP ON
PENN. R. R. TUNNELS: PLANT FOR EAST RIVER TUNNELS.

POWER PLANT, EAST RIVER TUNNELS, MANHATTAN.

1 Low Pressure Compressor.
2 " " "
3 " " "
4 " " "
5 " " "
6 " " "
7 Combination High and Low Pressure Compressor.
8 Class A High Pressure Compressor.
9 " H.C. " "
10 Stirling Boiler Original Installation.
11 Stirling Boiler Installed in 1906.
12 160 K.W. Electric Generator.
13 75 K.W. " "
14 High Pressure Hydraulic Pumps.
15 Low Pressure Hydraulic Pumps.
16 Blowers and Engines for Forced Draught for Original Boilers.
17 Blower and Engine " " " " Sixth Boiler.
18 After Cooler for Individual Compressors.
19 After Cooler for Tunnel Mains.
20 Low Pressure Receiver.
21 Class C High Pressure Receiver.
22 Class A " " "
23 Class H.C. " " "
24 Condensers.
25 Hot Well.
26 Hot Well Pumps.
27 Cochran Feed Water.
28 Oil Separators.
29 Feed Water Pumps.
30 Pump for Condenser Circulation.
31 Edwards Air Pump.
32 Pump for Condenser Circulation.
33 Emergency Pump for Feed Water.
34 Accumulator.
35 Ash Hoists.
36 Pit Pump.
37 Air Intake.
38 Water Tank.







One Flather shaping machine, 14-in. stroke,

Six Buffalo, No. LO, stationary forges.

On the Manhattan side, Fig. 22 and Plates XVIII, XX, and XXI, show the arrangement of the gantry and the comparatively small amount of ground available for carrying out the work. As there was little room for the storage of segments at this side, a portion of land was leased behind the boiler-house at Long Island City, where a large stock of tunnel segments was stored. These were shipped to Manhattan from time to time as required.

Permission was obtained from the Dock Department of New York City to lengthen the dock by 60 ft. This made room for two scows alongside the dock, but, owing to the Long Island Railroad rebuilding its ferry-slips and cutting off the northern side of the dock, the space available was not all that could be desired. Two medical air-locks and a doctor's office were erected near the office building. The powder magazine was placed at the end of the dock, as far from the plant as possible. A workshop under the gantry contained the following machines:

One Sibley and Ware drilling machine, back-gear, power-feed, 20 in., table 16 in. in diameter,

One Fosdeck radial drill, 2½ ft.,

One Harrington gap lathe, 28 and 48 in., compound rest, geared face-plate, 20-ft. bed, length between centers, 8 and 15 ft.,

One 24-in. Fitchburg lathe, 10-ft. bed,

One Acme bolt-cutting machine, No. 2, complete,

One Jarecki pipe-cutting machine, No. 11, 1 to 6 in., also for bolts ½ in. to 2 in.,

One Fisher punching and shearing machine, punching ¾-in. hole and shearing plate 20 in. deep,

One Bell standard guide steam hammer, with anvils and dies, 5 by 18 in. cylinder, 3 ft. 11 in. by 2 ft. 6 in. bed, height, 8 ft. 2 in., anvil weight, 2 200 lb.,

One saw bench,

One Fay and Egan, No. O, band saw, wheel diameter, 36 in.,

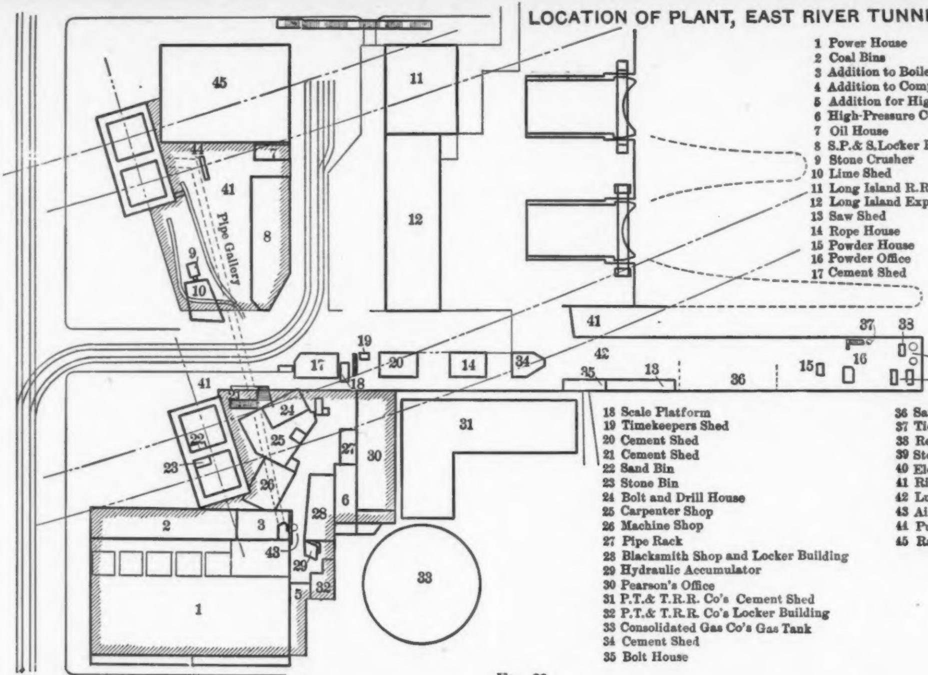
One heavy swing saw, 30 in.,

One Ajax drill sharpener, complete, with drills, dies, and dollies,

One Powis and Bale shaping machine, 12-in. stroke,

Four No. OH, stationary forges.

LOCATION OF PLANT, EAST RIVER TUNNELS, MANHATTAN



1 Power House
2 Coal Bins
3 Addition to Boiler Room
4 Addition to Compressor Room
5 Addition for High-Pressure Hydraulic Pumps
6 High-Pressure Compressor House
7 Oil House
8 S.P.& S.Locker Building
9 Stone Crusher
10 Lime Shed
11 Long Island R.R.Station
12 Long Island Express Shed
13 Saw Shed
14 Rope House
15 Powder House
16 Powder Office
17 Cement Shed
18 Scale Platform
19 Timekeepers Shed
20 Cement Shed
21 Cement Shed
22 Sand Bin
23 Stone Bin
24 Bolt and Drill House
25 Carpenter Shop
26 Machine Shop
27 Pipe Rack
28 Blacksmith Shop and Locker Building
29 Hydraulic Accumulator
30 Pearson's Office
31 P.T.& T.R.R. Co's Cement Shed
32 P.T.& T.R.R. Co's Locker Building
33 Consolidated Gas Co's Gas Tank
34 Cement Shed
35 Bolt House
36 Sand Pile
37 Tide Gauge
38 Resistance Box
39 Steam Pump for Air Coolers
40 Electric Pumps
41 Ring Storage
42 Lumber Pile
43 Air Cooler
44 Pug Mill
45 Radley Building

Fig. 22.

Mr. W. De Lacy, as Mechanical Engineer, was in charge of the Manhattan plant, with Mr. W. Newall as Master-Mechanic; at Long Island City and East Avenue, Mr. W. Y. Lewis, and later Mr. E. L. Pledger, was in charge, with Mr. L. Nicholson and Mr. Joseph Varry as Master-Mechanics. Mr. A. Hjort, as Electrical Engineer, was in charge of all the electrical equipment.

Great credit is due to Mr. J. H. Jowett and Mr. A. Hoffman, of the Ingersoll-Rand Company, for their original layout of the piping arrangements for the power plants, which had much to do with the economical results obtained.

The writer is indebted to Alfred Noble, Past-President, Am. Soc. C. E., Chief Engineer of the East River Division of the Pennsylvania Tunnel and Terminal Railroad, and to E. W. Moir, M. Am. Soc. C. E., Vice-President of S. Pearson and Son, Incorporated, New York, the Contractors who built the tunnels, for permission to write the paper and for the use of the drawings and photographs; he is also indebted to the manufacturers of the plant who have supplied plans.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1161

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE LINING OF THE FOUR PERMANENT SHAFTS OF THE EAST RIVER DIVISION.*

BY F. M. GREEN, ASSOC. M. AM. SOC. C. E.

The four shafts described in this paper were intended, not only to facilitate the construction of the tunnels, but to serve various purposes after their completion. It is of the latter that this paper treats.

The locations of the shafts are shown on Plates XIII and XIV† (accompanying the paper by Alfred Noble, Past-President, Am. Soc. C. E.). It will be seen that the shafts, being placed near the shore on each side of the river, divide the length of the tunnels into three portions: The first portion extends from the station at Seventh Avenue, under Manhattan Island, to the East River, the second lies almost wholly under the river, and the third extends from the river bank eastward under Long Island to the portals. This arrangement of shafts was advantageous for construction purposes. It possesses also some advantages from the point of view of the operation of the tunnels.

A description of these shafts, as used during the construction of the tunnels, is given in the paper‡ by Messrs. James H. Brace, Francis Mason, and S. H. Woodard, Members, Am. Soc. C. E. The work herein described was carried out after the completion of the tunnels.

* Presented at the meeting of September 21st, 1910.

† *Transactions*, Am. Soc. C. E., Vol. LXVIII, pp. 71 and 73.

‡ *Transactions*, Am. Soc. C. E., Vol. LXVIII, p. 419.

FIG. 1.—FORM FOR FRESH-AIR DUCTS, TUNNEL END.

FIG. 2.—FORM FOR FRESH-AIR DUCTS, SHAFT END.

During the operation of the tunnels the shafts will be required to perform the following functions:

1. To promote ventilation,
2. To provide access to and egress from the tunnels,
3. To permit electrical connections,
4. To provide for pump discharge.

The permanent lining of each shaft was designed to retain the sides of the shaft and to be of such form as to meet the requirements of the four functions enumerated above.

Ventilation is promoted by the piston action of the moving trains. When a train enters the tunnel a plenum is produced in front of the moving train. This region of plenum extends for a great distance in advance, in fact to the nearest shaft or portal. At each shaft a vertical opening 18 ft. in diameter was provided. As soon as a condition of plenum is produced in the tunnel by the entrance of a train, a strong upward current of air may be observed in the shaft. This continues while the train is approaching the shaft. A condition of partial vacuum exists in the tunnel in the rear of a departing train. As soon as a train has passed the shaft the current of air in the shaft is reversed. Fresh air continues to blow down the shaft until the train emerges from the tunnel at a portal, or until it passes another shaft.

Vertical openings have been provided in the shaft lining to serve as ducts for the mechanical injection of fresh air. This is delivered into the tunnels through nozzles which have been constructed in the sides of the tunnels where they pass out of the shafts. The nozzles are pointed in the direction of movement of the train, that is, they are pointed eastward in tunnels used for east-bound traffic and westward in tunnels used for west-bound traffic.

Access to and egress from the tunnels is provided for by three spiral stairways at each shaft. There is a bench on each side of each of the two tunnels that pass through a shaft. It is desirable to gain access to any bench without crossing a track. For this reason, in each shaft, one stairway was provided to the north bench of the north tunnel, one to the south bench of the south tunnel, and one to serve the adjacent benches of the two tunnels.

Wrought-iron pipes, $3\frac{1}{2}$ in. in diameter, for electric conduits, were embedded in the concrete of the shaft lining in a vertical position. In each shaft they were arranged in four groups, two for power cables

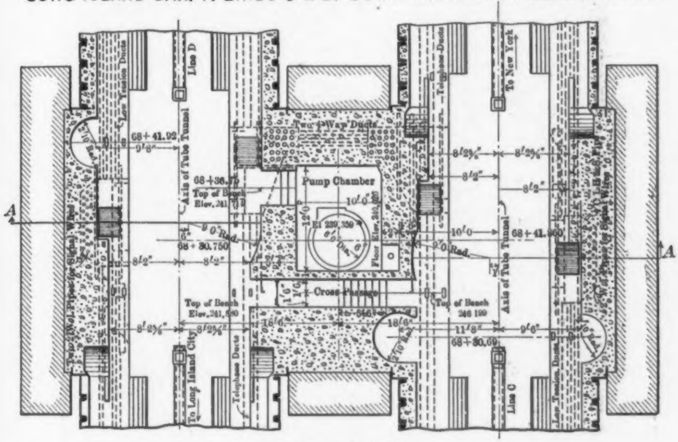
and two for telephone and telegraph cables. The pipes for power cables were separated into sections by pockets left in the concrete, where provision was made for supporting the cables, thus reducing the weight of the cable suspended from the top. Wrought-iron pipes, 2 in. in diameter, were embedded in the concrete to serve as conduits for lighting and signal wires.

Water seeping into the tunnels, from the Station to the East River and from those under Long Island, runs down grade to the shafts, where it is collected in sumps under the tracks. From the sumps it is pumped to the tops of the shafts through cast-iron discharge pipes embedded in the concrete lining. The pumps are in pump-chambers formed in the concrete between the tunnels as shown in Fig. 1.

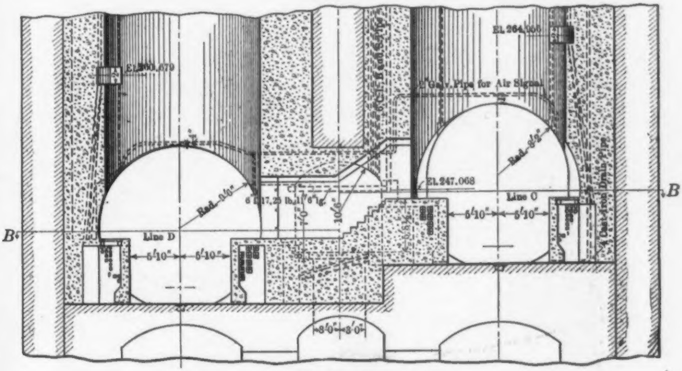
The concrete lining, as a retainer of the sides of the shaft, is illustrated in Fig. 2. This is a sectional plan of the South Manhattan shaft taken at a point a few feet above the tunnel roof. In the Long Island shafts, the caissons were sunk to a point below the tunnels, while, in the Manhattan shafts, the caissons were stopped in rock above the tunnel roof. These different types of construction are shown in Figs. 4 and 5. In the Long Island shafts, the inner shell of the caissons forms the water-proofing surface; in the Manhattan shafts, it was necessary to provide water-proofing below the caissons. With this end in view, a wall of concrete was built against the rock. When this had set, the forms were removed and the surface was plastered smooth with cement mortar. On the surface thus prepared, felt and pitch water-proofing was placed, six layers of felt and seven of pitch. Against the felt and pitch water-proofing the concrete of the shaft lining was deposited. This was required to be of such strength that it could safely withstand the pressure of water on the outside of the water-proofing, which, at the maximum depth, is probably not greater than 40 lb. per sq. in.

Some interesting problems arose in connection with the preparations for, and the construction of, the concrete wall upon which the felt and pitch water-proofing was to be placed. It was necessary that this wall should be dry before any hot pitch was placed upon it. Water was issuing from fissures in the rock at several points. At these fissures, vertical tile drains were built against the rock, and a short piece of pipe was run out horizontally from the base of each vertical drain, to discharge the water beyond the face of the wall. A corrugated

LONG ISLAND SHAFT. LINES C & D. CONSTRUCTION AT BENCH LEVEL.



SECTIONAL PLAN *B-B*



CROSS-SECTION *A-A*

FIG. 1.

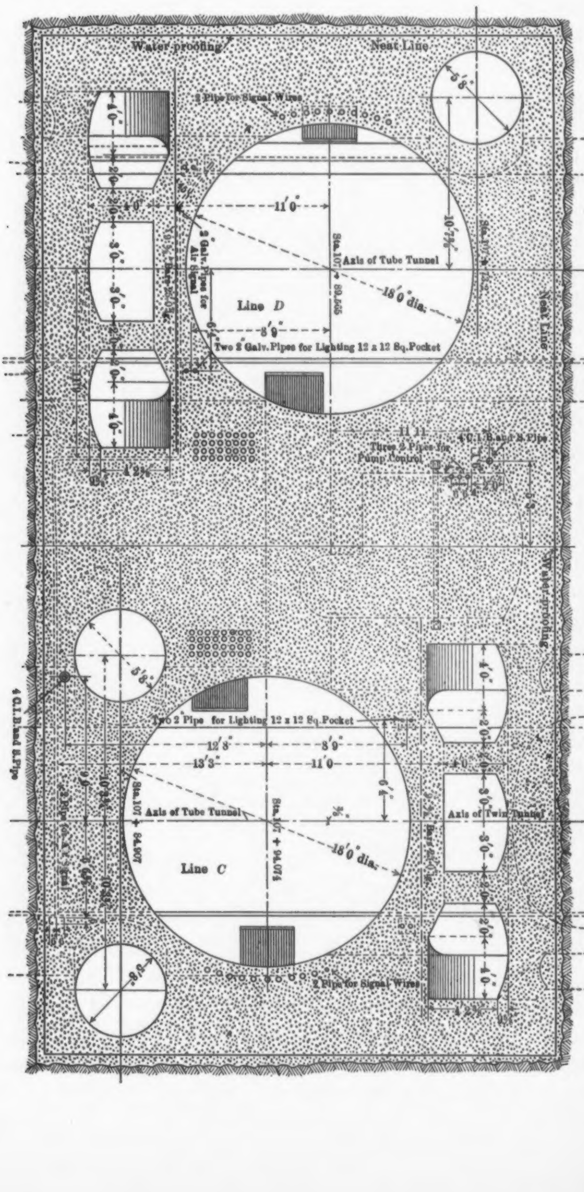
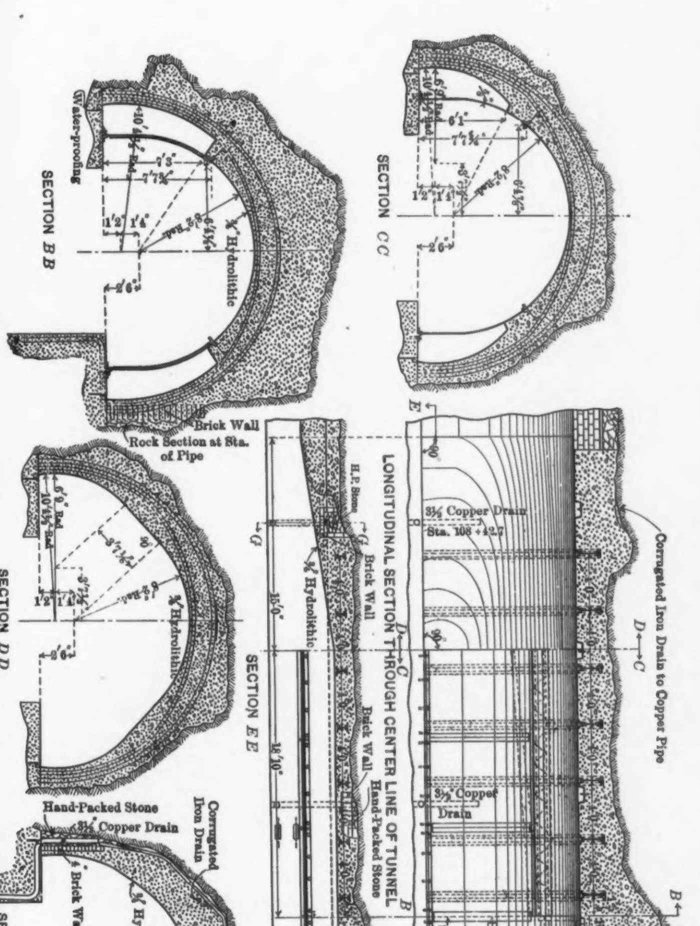


FIG. 2.

MANHATTAN SHAFT, LINES *C* AND *D*, SECTION ABOVE TUNNEL ROOF.



NOZZLES IN TUNNEL C WEST OF MANHATTAN SHAFT

Fig. 8.

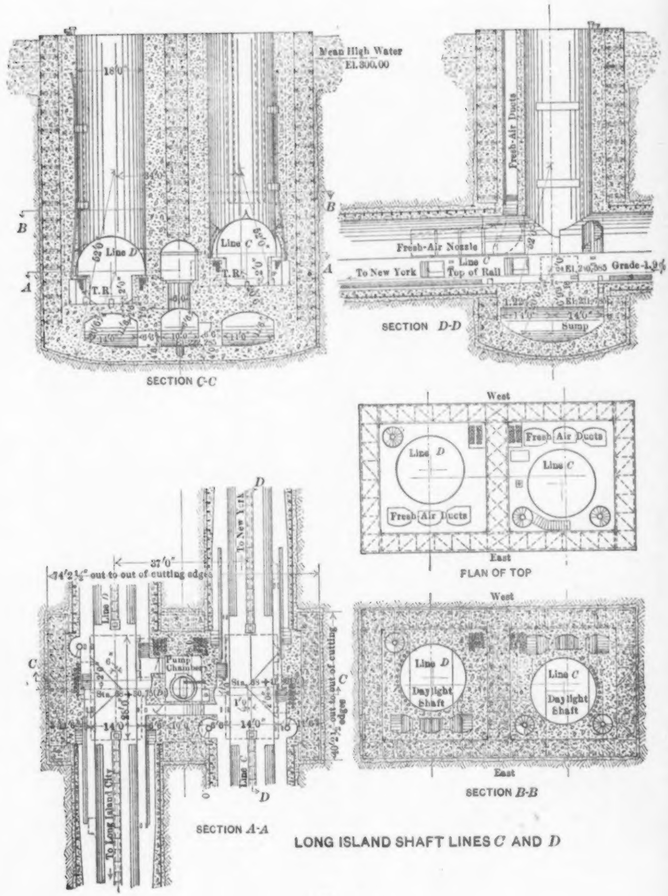
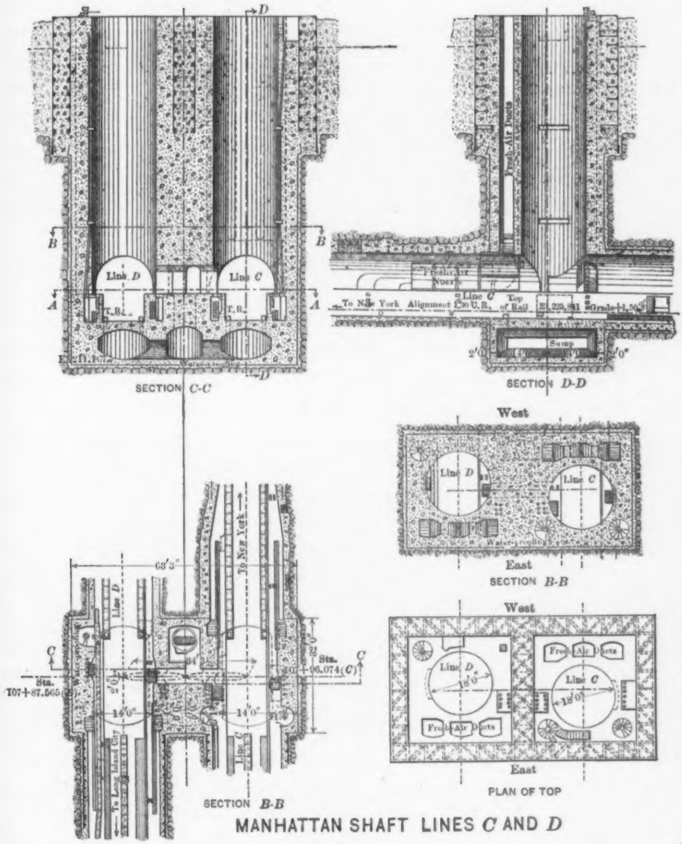

Mean High Water
El. 300.00
SECTION C-C
SECTION D-D
Fresh-Air Ducts
Fresh-Air Nozzle
To New York
Line C
Top of Rail
Grade-1.9%
Sump
West
East
PLAN OF TOP
Line D
Line C
Fresh Air Ducts
SECTION B-B
Daylight Shaft
Pump Chamber
To New York
To Long Island City
SECTION A-A
LONG ISLAND SHAFT LINES C AND D

FIG. 4.



MANHATTAN SHAFT LINES *C* AND *D*

FIG. 5.

iron roof was built over the location of the wall, to shed the water that dripped from above. After the concrete had been deposited and the forms had been stripped off, the felt and pitch water-proofing was placed, excepting over the small openings where the horizontal pipes issued from the wall. The water was allowed to run from these pipes, thus relieving the pressure at the back of the water-proofing, until everything was in readiness for depositing the concrete for the shaft lining. Then the pipes were plugged and patches of felt and pitch water-proofing were put over the holes, and at the same time the vertical pipes were poured full of pitch from above. The fresh concrete was deposited against the water-proofing as rapidly as practicable, so as to counteract the tendency of the water to accumulate outside and force the felt and pitch inward.

At the east face of the South Manhattan shaft, when making preparations to place the felt and pitch water-proofing, it became necessary to drain away water that was running down over the face of the wall from the exposed rock above. To accomplish this, a drain was constructed on the face of the wall near its top. This consisted of a strip of tin set in a ridge of plaster of Paris stuck on the face of the wall. The drain was nearly horizontal, but had a grade downward to the south. It answered the purpose very well, allowing the wall to dry out below the drain. This type of drain was found useful at many points. It could be applied quickly and at small cost.

The concrete lining had been placed in the iron-lined tunnels east of the Long Island shafts previous to the time when the design for the ventilating apparatus was determined upon. Therefore it became necessary to remove a sufficient quantity at the sides of the arches, in the two tunnels to be used for east-bound traffic, to provide space for the fresh-air nozzles.

It was considered unwise to use explosives in this work, on account of the danger of breaking the cast-iron segments.

By experiment it was found that the concrete could be broken out in fragments by the following process: Holes were drilled in the concrete, about 4 in. apart on a horizontal line, and perpendicular to the face. Parallel to the first row and about 8 in. above it, another row of holes was drilled, the holes being pointed downward at an angle of about 40 degrees. Steel wedges were driven into the upper holes, and resulted in breaking out wedge-shaped pieces of concrete.

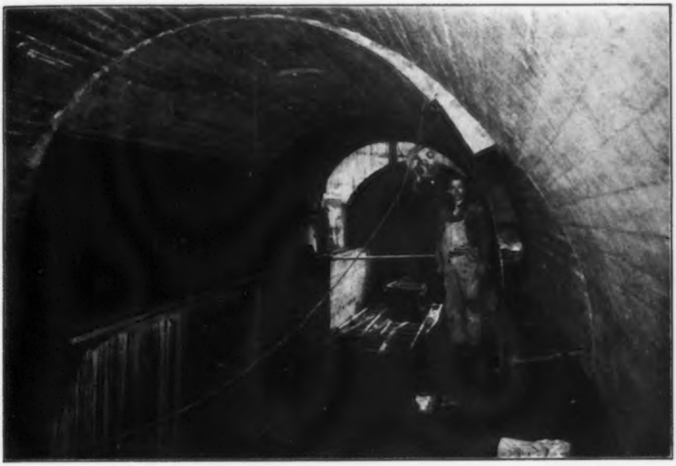


FIG. 1.—FRESH-AIR NOZZLES.

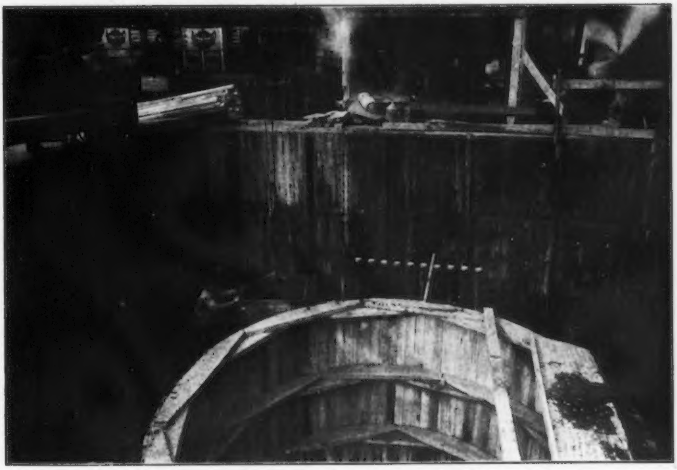


FIG. 2.—FORMS FOR OPEN WELL.

Another row of inclined holes was drilled about 8 in. above the second row. Steel wedges driven into the holes of this row broke out other fragments of concrete. This process was continued until the space for the nozzle was roughened out to approximately its final dimensions. It was then finished to nearly its final form by chisels operated by air hammers, and smoothed up with a stone-axe operated by hand.

In each tube this work required the removal of about 14 cu. yd. of material. The cost of this removal was about $72.50 per cu. yd., including the work of finishing the surface. The surface dressed was 515 sq. ft. The average depth of cutting was about 9 in. The cost was about $2 per sq. ft. of surface dressed, including the removal of material.

The construction herein described was done under contract by Fraser, Brace, and Company, of which both the President, Charles E. Fraser, and the Secretary, James H. Brace, are Members of the American Society of Civil Engineers. Work was started on September 27th, 1909.

The contractor's plant consisted of derricks, boilers, hoisting engines, narrow-gauge track, small dump-cars, rotary mixers, cement sheds, and other apparatus of the usual type.

Forms for splicing chambers, air-nozzles, and other parts were built in sections on the surface and lowered to position in the shafts.

Figs. 1 and 2, Plate XXII, show some of these forms in process of construction. Fig. 1, Plate XXII, is a view of the tunnel end of the form for the fresh-air ducts. The inner arch form has the dimensions of the intrados of the standard single-track tunnel under Manhattan. The outer arched form is for the outside of the air-nozzle. (See Fig. 1, Plate XXIII.) The space between is the area available for the jet of air. The upper part of this form is to mould the base of the air ducts. Fig. 2, Plate XXII, is a view of the shaft end of the same form. When this form was placed in position in the shaft, the lagging on the semicircular arch was replaced by the ⅝-in. steel plates of the nozzles, forming a complete steel arch at the base of the air ducts, as shown in the background in Fig. 1, Plate XXIII. It will be seen that the fresh air, on arriving at the top of the tunnel on its way down the shaft, is separated into two streams, one going into the nozzle on the north side of the tunnel and the other into the nozzle

on the south side. Fig. 1, Plate XXII, is a view of the fresh-air duct at the roof of the tunnel.

Fig. 2, Plate XXIII, shows the forms used in constructing the open wall, 18 ft. in diameter. The form here shown was 8 ft. deep. It was set at a higher elevation for each additional section of concrete. In this view it is near the top of the North Manhattan shaft.

The concrete in the lower portions of the shaft lining was mixed in the proportions of 1 part cement, 2½ parts sand, and 5 parts stone.

The sand and stone were measured in a steel dump-car. A partition was constructed across the hopper, dividing it into two portions, one containing 6.55 cu. ft. and the other 13.10 cu. ft. Three bags, or 285 lb., of cement were used with each car of sand and stone.

The concrete in the upper portions of the shaft lining (above a horizontal plane 3 ft. above the tunnel roof) was mixed in the proportions of 1 part cement to 3 parts sand, and 6 parts stone. Each batch contained 7.86 cu. ft. of sand, 15.72 cu. ft. of stone, and three bags, or 285 lb., of cement. A portion of this concrete was mixed in 4-bag batches, each batch containing 10.5 cu. ft. of sand, 21.0 cu. ft. of stone, and four bags, or 380 lb., of cement.

Fresh-air nozzles were constructed in the tunnels immediately west of the Manhattan shafts, in Lines *A* and *C*. The tunnels were excavated to full section in rock. The roofs were then constructed as shown in Fig. 3. The fresh-air nozzles, being formed in the side-walls of the arch, cut away the skewback and haunches of the arches to such an extent that it was deemed wise to reinforce the concrete arch with steel ribs built of plates and angles. These are shown in Fig. 3.

The interior of the concrete arch was thoroughly water-proofed with Hydrolithic water-proofing. In addition to this, copper drain-pipes, 3½ in. in diameter, were placed in the positions shown on the plans, the inlet end of each copper pipe being located in a chamber, with brick walls built against the rock at points where running water was found. The chamber was filled with broken stone. At one point where running water was encountered in the roof, a drain was constructed by hanging sheets of corrugated iron against the rock surface and training them so as to run the water into the rock-packed chamber. The sheets of corrugated iron were clamped securely to the rock by anchor-bolts set in holes drilled in the rock. The corrugation formed the channels for conveying the water. The sides and ends of the corrugated-iron drain were thoroughly and carefully sealed with Portland cement

FIG. 1.—FRESH-AIR DUCT.

FIG. 2.—REMOVING CONCRETE FROM TUBE TUNNEL.

mortar so as to prevent any grout from entering the drain while the concrete was being placed. The measures taken to drain away the water from the wet spots in the rock appear to have been adequate, as water is flowing from the lower ends of the copper pipes, and no moisture is to be seen at these points in the tunnel roof.

At the east end of the Manhattan shaft the felt and pitch water-proofing of the shaft was connected to the cast-iron tunnel lining so as to make the water-proofing surface continuous. A coating of hot pitch was applied to the flange of the tube tunnel. The felt was lapped over this and securely clamped in place by steel plates bolted on with 1¼-in. bolts.

The felt and pitch water-proofing of the shaft was carried up on all four sides of the shaft to a point 7 ft. above the cutting edge of the caisson. Above this elevation, the inner steel plates of the caisson constitute the water-proofing.

The spiral stairways were constructed in circular wells, 5 ft. 8 in. in diameter, formed in the concrete. No attempt was made to form steps in the concrete, or to place supporting brackets, during the construction of the wells. This made the operation of setting the forms for the wells very simple.

The stairs were constructed of cast iron; the treads, carriers, and newel posts being cast and machined to standard patterns and templets. The twelve stairways have an aggregate height of 831 ft.; they contain 1 224 carriers, all alike, and 1 172 treads, all alike. The rise of each stair was divided into flights by landings placed at intervals of about 11 ft. 4 in. Each landing occupies a quadrant of a circle. The inner end of each tread is supported by the newel post, the outer end by the carrier. A supporting bracket was bolted to the concrete at each side of each landing, and also under one of the carriers about midway between landings.

The last batch of concrete was placed on March 11th, 1910. The work on the permanent structure was completed on May 31st, 1910, on which date the spiral stairways were finished.

The principal items of the permanent linings of these shafts comprise:

12 500 cu. yd. concrete,
14 400 sq. ft. of felt and pitch water-proofing,
5 000 sq. ft. of Hydrolithic water-proofing,

73 600	lb. steel, reinforcing concrete,
196 000	lb. steel in ventilator nozzles,
26 400	lin. ft. of steel pipe,
12 000	lb. of cast-iron pipe,
12 400	duct ft. of vitrified electric conduits,
132 400	lb. cast-iron spiral stairways.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

TRANSACTIONS

Paper No. 1162

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE LONG ISLAND APPROACHES TO THE EAST RIVER TUNNELS.*

By George C. Clarke, M. Am. Soc. C. E.

The portion of the Pennsylvania Railroad Tunnel Extension into New York City described in this paper extends from East Avenue to Thomson Avenue, in Long Island City, Borough of Queens, and covers that portion of the work on which the line changes from an underground to a surface railroad, and the entrance to the Sunnyside Yard.

The work consisted of 6 950 lin. ft. of cut-and-cover tunnel; 2 555 lin. ft. of retaining wall and invert approach to tunnels; one overhead highway bridge at Hunter's Point Avenue; one single-track steel viaduct and one double-track viaduct, both with concrete floors and the latter having a concrete approach; grading for surface tracks and streets, and a drainage system requiring 367 000 cu. yd. of excavation, of which 61 000 cu. yd. were rock; the placing of 145 000 cu. yd. of concrete, containing 1 520 tons of reinforcing bars and covered by 664 000 sq. ft. of felt and pitch water-proofing, six-ply in thickness; 215 000 lin. ft. of piles in foundations; 217 000 lin. ft. of electric ducts; 18 000 lin. ft. of cast-iron and vitrified drain pipe of various sizes, and 2 400 tons of structural steel.

* Presented at the meeting of September 21st, 1910.

Alignment and Grades.

At East Avenue the four tunnels lie in the same order as that in which they leave the Terminal Station in Manhattan, Tunnel *A* being the northernmost and Tunnel *D* the southernmost tube, and, although the two pairs are much closer together than through Manhattan, the distances from center to center of the tubes being, *A* to *B* 30 ft., *B* to *C* 28 ft., *C* to *D* 32 ft., and the bearing of the southerly pair slightly more to the north than that of the northerly pair, they still comprise in effect two double-track railroads, *A* and *C* being west-bound, and *B* and *D* east-bound tracks. They are at that point all on 1° 30′ curves. The alignment and grades are shown on Plate XXV.

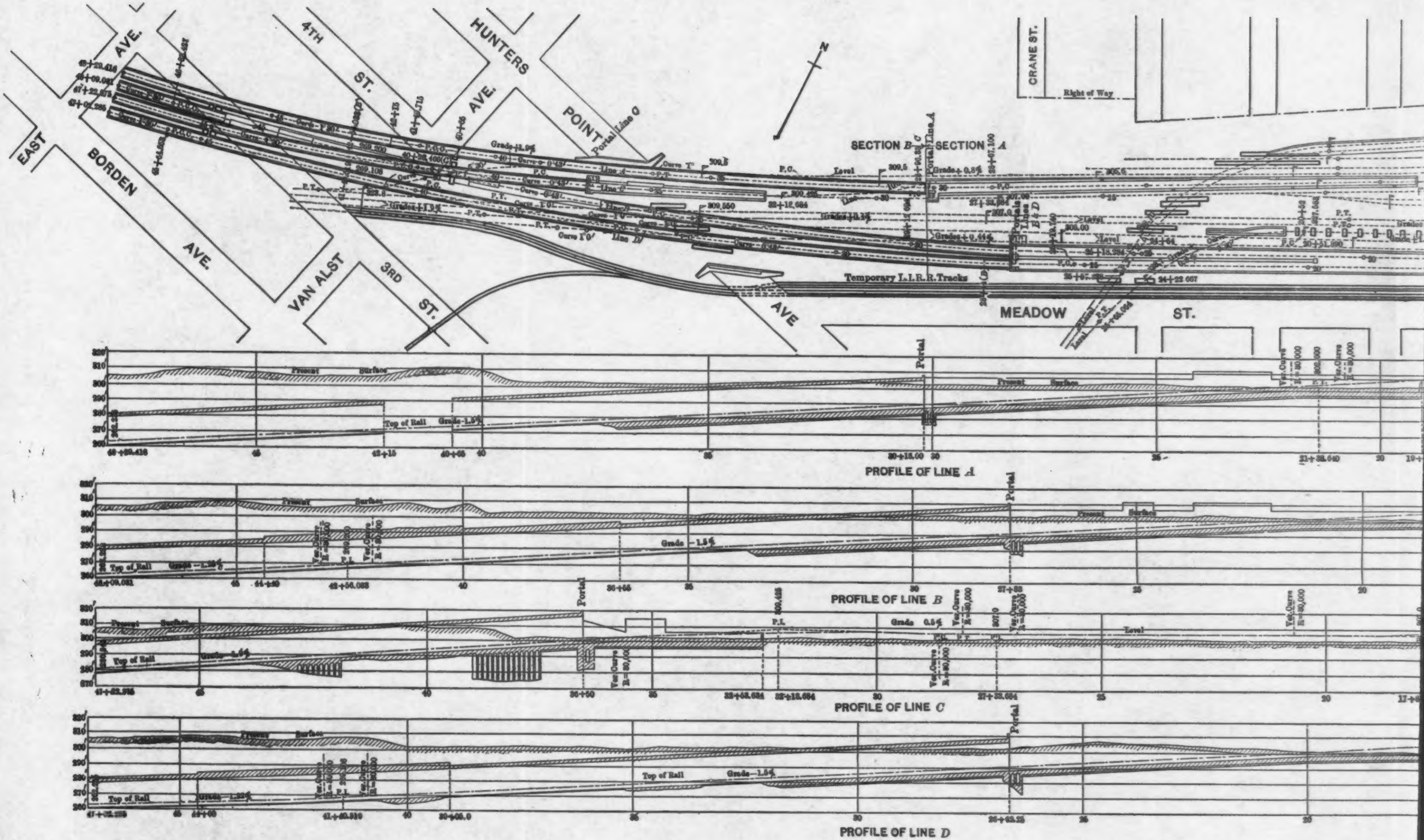
In elevation of tracks, *A, B,* and *D* are the same, the top of rail being 46 ft. below the surface, and the grades 1.5, 1.25, and 1.22%, respectively, while *C* is but 27 ft. below the surface, and on a 1.9% grade.

East from East Avenue, Tunnels *A* and *C* continue on the 1° 30′ curve for a distance of about 700 ft., then they compound into 43′ curves which continue to beyond the portals and bring the lines into parallel tangents side by side, whereas Tunnels *B* and *D* compound from the 1° 30′ curves to 43′ curves within 180 ft. of East Avenue, thus throwing them to the south and causing *B* to pass under *C* and approach *D* until they emerge through a joint portal at a distance of 2 060 ft. from East Avenue into slightly converging tangents, at which point Line *B* is 115 ft. distant from Line *C* and the four lines form a right-hand four-track railroad, in which order they continue into the Sunnyside Yard.

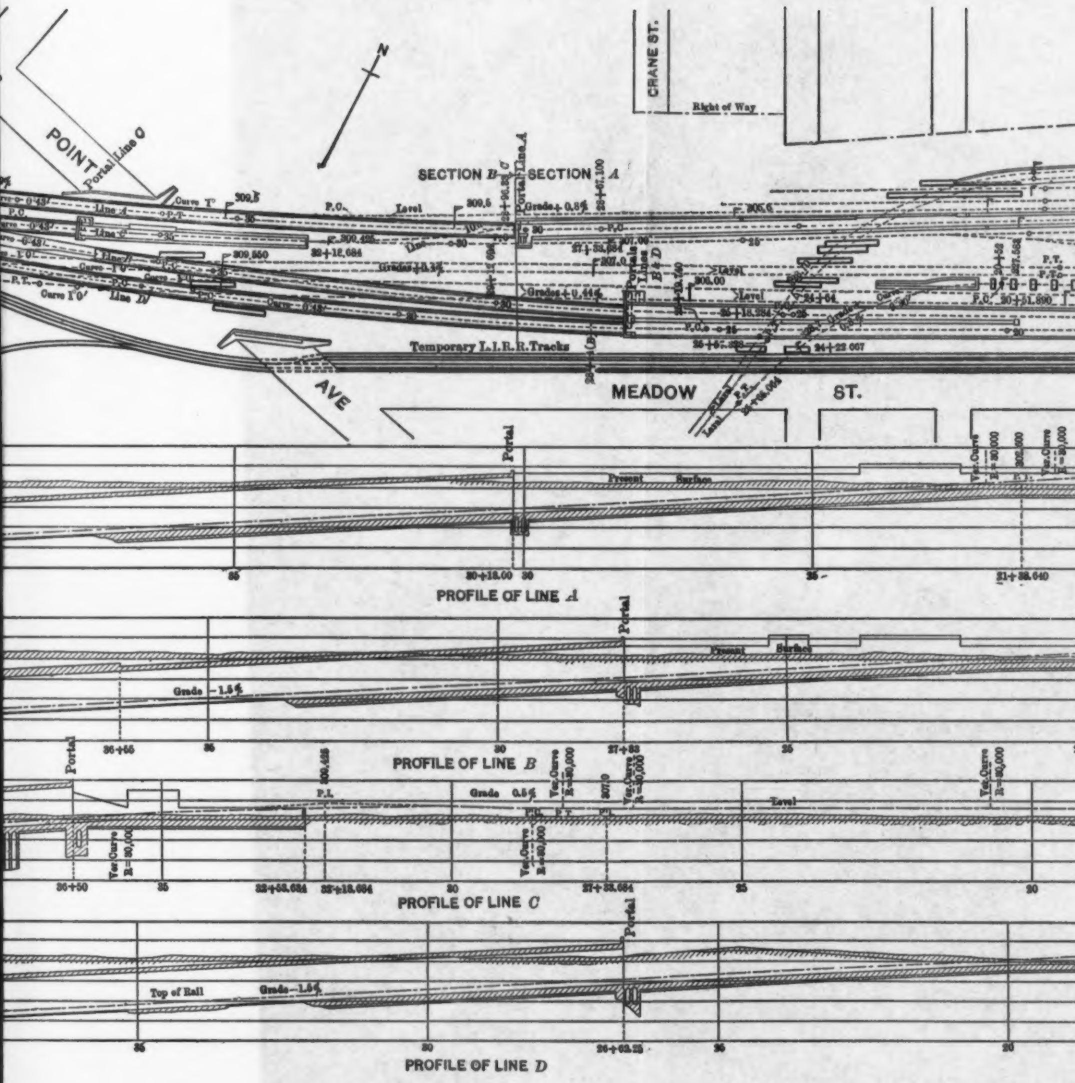
The portal of Line *A* is slightly west of the joint portal for Lines *B* and *D,* being 1 815 ft. from East Avenue, whereas the heavier grade on Line *C* brings its portal just west of Hunter's Point Avenue, and 1 100 ft. from East Avenue.

Design.

The clearance line in the tunnels above top of rail is identical for all sections, and very similar to the single-track tunnels under Manhattan, but the varying conditions of foundation and adjoining structures required variations in both floor and arch roof. Fig. 1 shows two typical sections. Where the structure is on a rock foundation, as

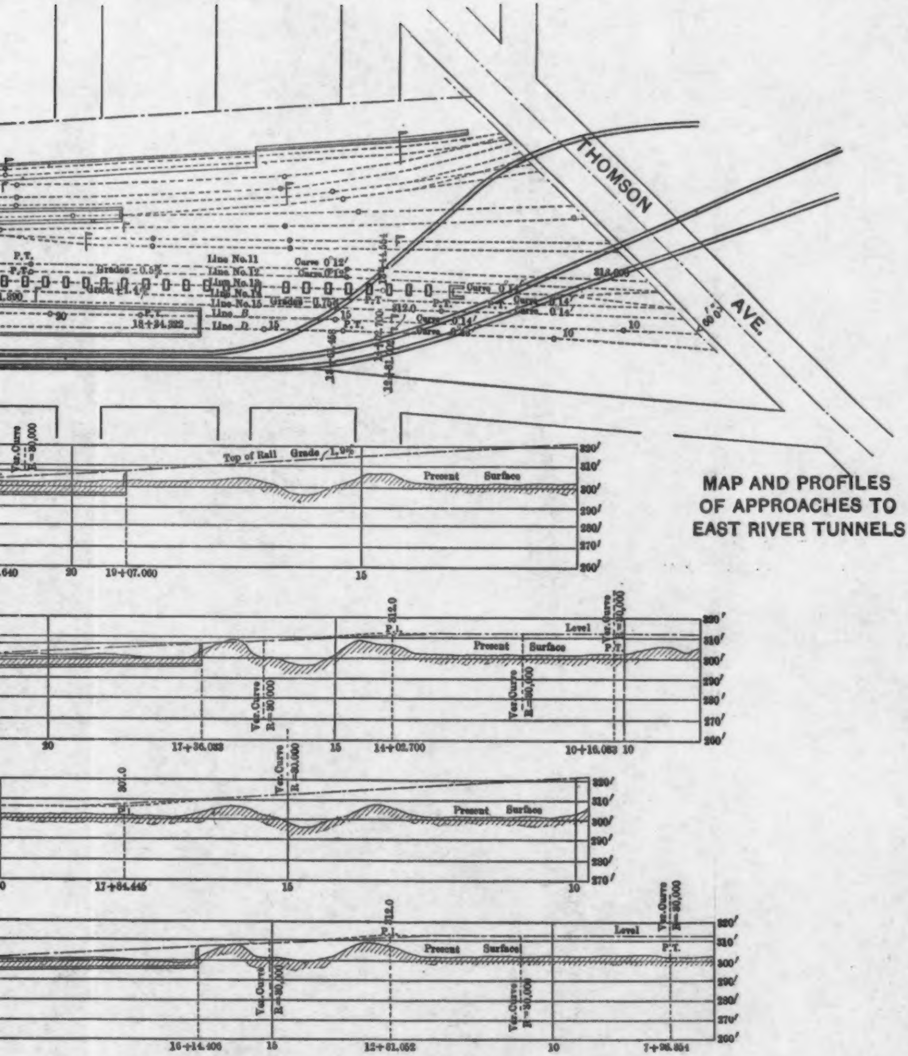


EAST
AVE.
BORDEN
AVE.
4TH
ST.
HUNTERS
POINT
AVE.
VAN ALST
3RD
ST.
AVE
CRANE ST.
Right of Way
MEADOW
ST.
N
Portal Line C
SECTION B, C
Portal Line A
SECTION A
Portals Lines B & D
Temporary L.I.R.R. Tracks
PROFILE OF LINE A
PROFILE OF LINE B
PROFILE OF LINE C
PROFILE OF LINE D



CRANE ST.
Right of Way
POINT
Portal Line C
N
SECTION B
SECTION A
Portal Line A
Portals Lines B & D
Temporary L.I.R.R. Tracks
AVE
MEADOW
ST.
Present Surface
PROFILE OF LINE A
Grade -1.5%
PROFILE OF LINE B
PROFILE OF LINE C
Top of Rail
Grade -1.5%
PROFILE OF LINE D

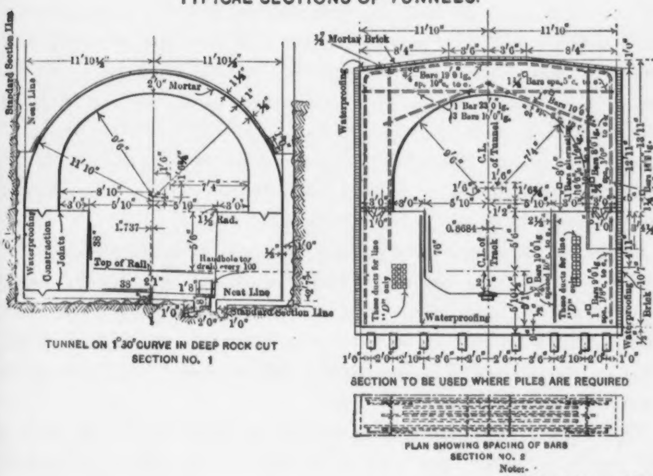
PLATE XXV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1162.
CLARKE ON
PENN. R. R. TUNNELS:
APPROACHES TO EAST RIVER TUNNELS.



MAP AND PROFILES
OF APPROACHES TO
EAST RIVER TUNNELS

shown in Section No. 1, the floor has a minimum thickness of 6 in. and is not water-proofed, but, where it is supported on piles, the floor necessary to distribute the load over the piles properly is heavy enough to resist the upward pressure of the water, and therefore the water-proofing is carried under the tunnel, being placed on a sub-base of 9 in. of concrete, 3 in. about the head of the piles and 6 in. over them. All the tunnels are water-proofed above the floor level, and in those supported on piles the water-proofing forms a complete envelope.

TYPICAL SECTIONS OF TUNNELS.



TUNNEL ON 1°30' CURVE IN DEEP ROCK CUT
SECTION NO. 1

SECTION TO BE USED WHERE PILES ARE REQUIRED

PLAN SHOWING SPACING OF BARS
SECTION NO. 2

Note:- All bars to be corrugated or twisted square steel bars.

FIG. 1.

Only in those sections where the original rock stood at an elevation of 5 ft. or more above the bench-wall, as in Section No. 1, Fig. 1, is any arch action required in the roof to make it stable; under all other conditions sufficient steel was put in the sides and top of the arch to make them stable as beams. The amount of reinforcement varied with the depth of cover and the position of the adjacent surface tracks; Section No. 2, Fig. 1, shows a typical section of tunnel on pile foundations. Tunnels built on rock, the original surface of which was less than 5 ft. above the bench-walls, are similar to that section above the top of rail and similar to Section No. 1 below that point.

The crossing of Tunnel *C* over Tunnel *B* required special sections. Where the tunnels approached each other from the west, Tunnel *B* was entirely in rock excavation, the original surface of which was either above or slightly below the floor of Tunnel *C;* little variation, therefore, was required, as shown by Fig. 2.

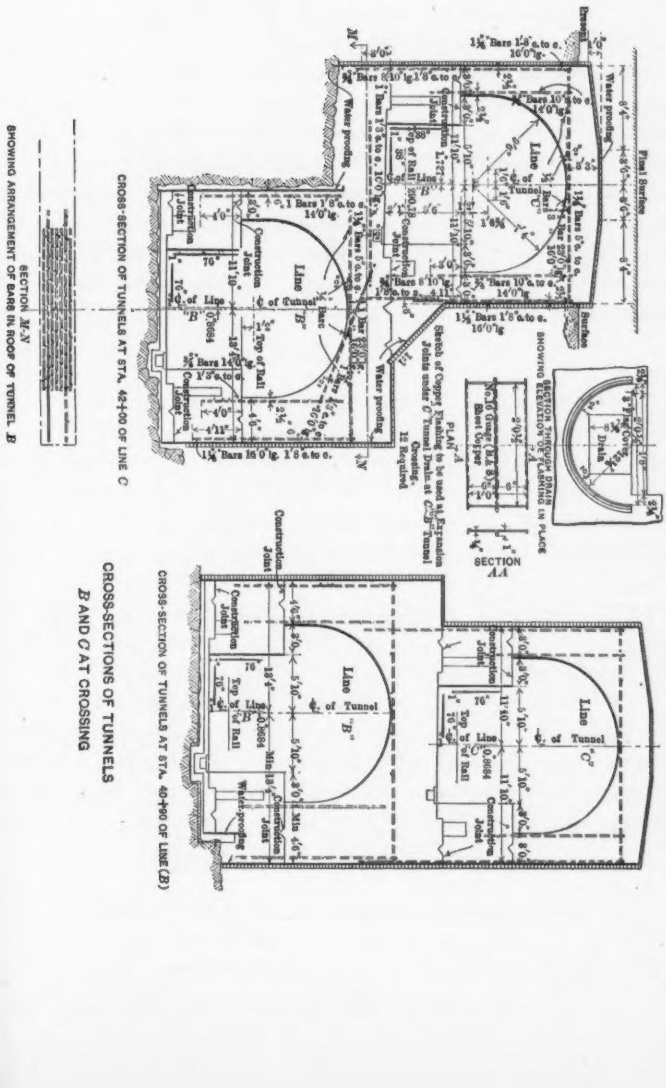
It will be noted that the only variation in these sections of either tunnel from the usual form consists of a thickening of the bench- and side-walls of Tunnel *B* and the batter given the bench-wall of Tunnel *C* in order to distribute the load over Tunnel *B*. Where Tunnel *C* left Line *B* toward the east the rock was much lower in comparison with Tunnel *C* and, to save concrete, the expedient was resorted to of supporting that portion of Tunnel *C* not resting on *B* on a cellular construction, formed by a series of jack-arches in conjunction with the north walls of Tunnels *B* and *C*, as shown by Fig. 3. After Tunnel *C* had entirely cleared Tunnel *B* the jack-arches were continued to the portal, the side-walls being omitted below the floor of *C*, thus forming a concrete viaduct by which Line *C* was supported.

It was not expected that the drain in Tunnel *C* at its crossing over Tunnel *B* would carry any water except when the sump at the portal might be allowed to overflow, and, to prevent leakage at such times through the joints between sections into Tunnel *B*, a copper flashing, shown on Fig. 2, was designed, with a bellows fold lying in the joint between sections to permit expansion.

The splicing chambers, refuge niches, ladders, etc., in all tunnels were similar in design and spacing to those in the cross-town tunnels under Manhattan.

At the several portals, there are sumps for catching the drainage from the inverts, together with chambers for the pumps necessary to care for that water; there are also concrete stairs from the surface to the bench-walls and tunnel floor. Plate XXVI shows three longitudinal sections and one cross-section of the *B-D* portal; the other portals are similar, but each is for a single tunnel.

The retaining wall and invert approaches to the tunnels are in form and effect practically dry docks, the material against which they protect the tracks being mud instead of water. Plate XXVII shows a plan and sections of the common invert for Lines *B* and *D*. Those for Lines *A* and *C* are for one track each, but are similar to that for



CROSS-SECTIONS OF TUNNELS
B AND *C* AT CROSSING

FIG. 2.

B-D with the portion between the center lines of *B* and *D* omitted and the 15-in. vitrified drain reduced to a 12-in. and placed in the side-wall opposite the ducts.

The inverts, with the exception of 40 ft. of Line *A* in the vicinity of the portal, are all supported on pile foundations, and the necessity of keeping the heads of the piles below the ground-water level required that the outer end of the invert be built on a flatter grade than the tracks, the intervening space between floor and base of tie, about 6 ft. at the curtain-wall, being filled with broken stone.

The purpose of the center-wall, built westward from Station 20 + 97 between Lines *B* and *D*, is to prevent the upward pressure of the mud from lifting and breaking the concrete floor, and, incidentally (as does each side-wall), it furnishes column foundations for the elevated freight lines crossing the yard.

Contractors.

As stated in the paper by Alfred Noble,* Past-President, Am. Soc. C. E., the work was done by Naughton Company and Arthur McMullen, with the exception of the steel and concrete superstructure of the viaducts, and a length of about 140 ft. of Tunnel *A*, at the intersection of Fourth Street and Van Alst Avenue, which was built by the Degnon Contracting Company in conjunction with its construction of the Steinway Tunnel which at this point rests partly on top of Tunnel *A*. The Secretary and Manager for the contractors was George W. McNulty, M. Am. Soc. C. E., and through the greater part of the work their Resident Engineer was C. W. S. Wilson, M. Am. Soc. C. E.

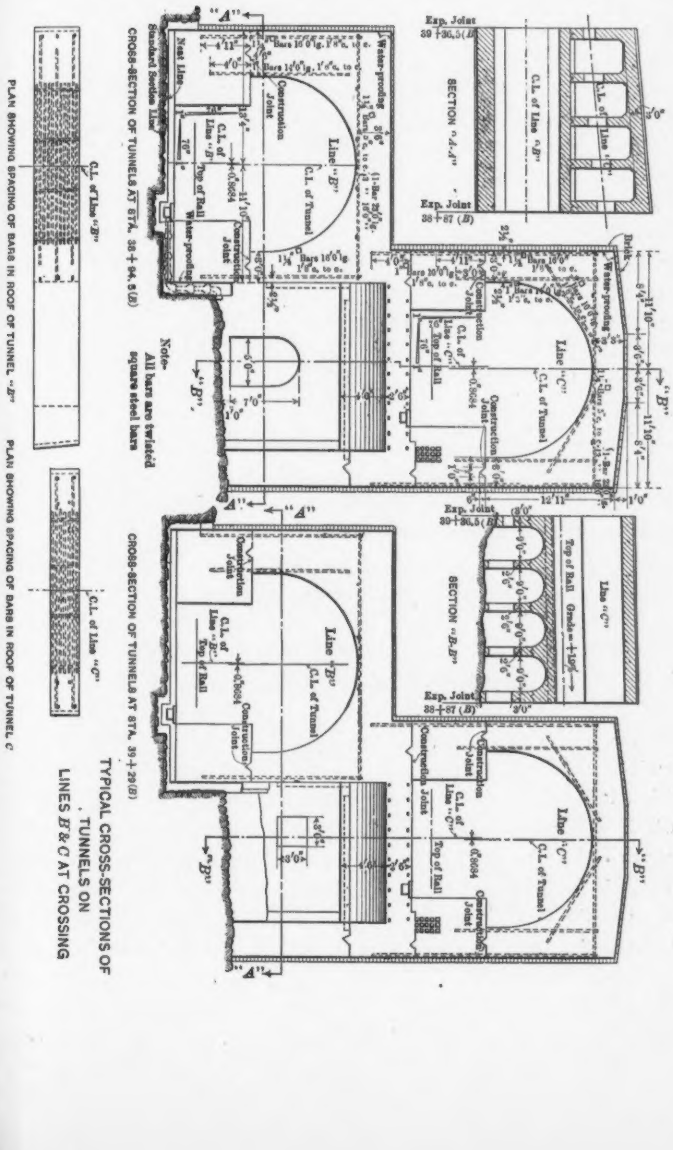
They began work on June 4th, 1907, and completed their contract on December 31st, 1909, with the exception of a small amount of cleaning up, which could not be finished until the Long Island Railroad tracks were moved from a temporary position which they occupied during most of the time that the work was in progress.

Condition of Ground at Beginning of Work.

The condition at the beginning of the work is shown on Plate XXVIII. The tracks of the Long Island Railroad occupied the surface on the line of portions of the work from Third Street near Van Alst

* *Transactions*, Am. Soc. C. E., Vol. LXVIII, p. 62.

Fig. 8.



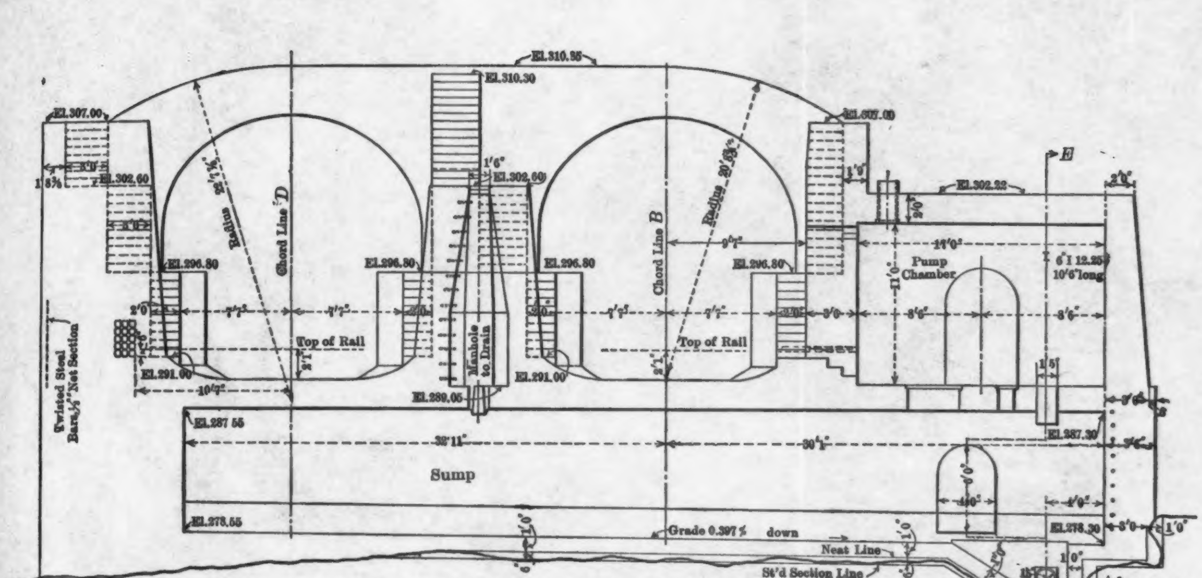
TYPICAL CROSS-SECTIONS OF TUNNELS ON LINES *B* & *C* AT CROSSING

FIG. 8.

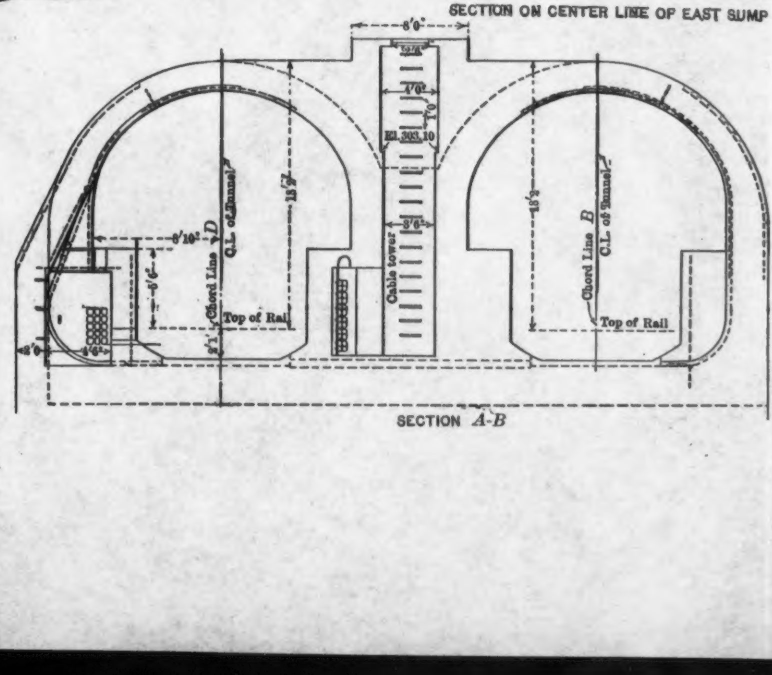
Avenue to Thomson Avenue, the elevation of the top of rail varying from 303 to 304 ft., or from 3 to 4 ft. above mean high tide. Hunter's Point Avenue crossed these tracks on a through truss bridge at an elevation of 322 ft., the length of the bridge being 85 ft. and the approaches to it on embankments, which on the northerly side of the bridge were practically level, but on the southerly side descended from the bridge on a 4% grade. Meadow Street had been graded to an average elevation of 307 ft. from Hunter's Point Avenue to Nott Avenue, and fills of varying widths existed on line of the cross-streets from Nott Avenue to Arch Street, extending from Meadow Street to within 20 or 30 ft. of the railroad tracks. The remainder of the area east of Van Alst Avenue was a swamp over which the water stood at an elevation of 302 ft., the depth varying from 0 to 4 ft. West of Van Alst Avenue the ground had all been filled and the swamp mud compressed to a thin water-tight stratum. The surface of the swamp was a bed of tough peat, and underlying it there was from 3 to 15 ft. of black swamp mud which when stirred up with water became perfectly liquid, but, in its original condition, was practically impervious. The fills made for the railroad and streets had displaced or compressed to a very thin layer the swamp mud in those particular locations.

Underlying Rock.

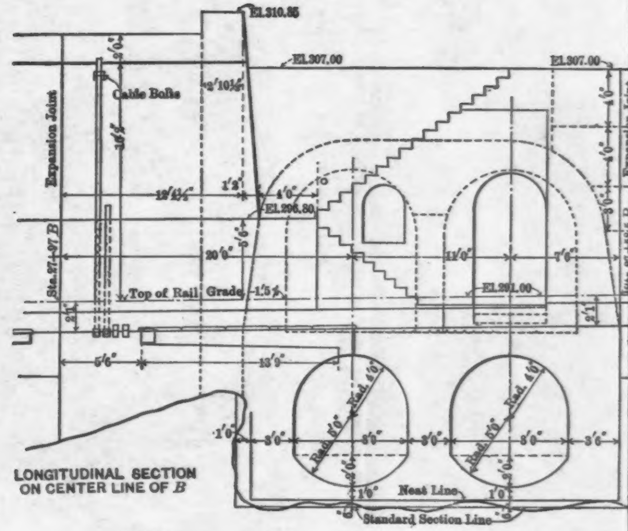
The elevation of the underlying rock varied greatly, rising to the sub-grade of the railroad tracks at Anable Avenue, from which point it sloped in all directions until it was about 40 ft. below the surface at Nott Avenue and from 40 to 60 ft. below between Davis and Arch Streets. West of Hunter's Point Avenue the rock rose rapidly again until at East Avenue the entire section of each tunnel, except *C*, was below its surface. Where the rock east of Hunter's Point Avenue lay within a few feet of the surface, the mud extended entirely to it, but, as the rock fell off, different strata of sand and clay were encountered. Toward the east, and south of the high point of rock at Anable Avenue, the sand predominated, and west and southwest of that point was found more clay which, toward Hunter's Point Avenue, contained many boulders, varying in size from a few cubic feet to 8 or 10 cu. yd. This stratum of clay was practically water-tight and quite firm when surface water was kept from it, but became "soupy" very quickly when



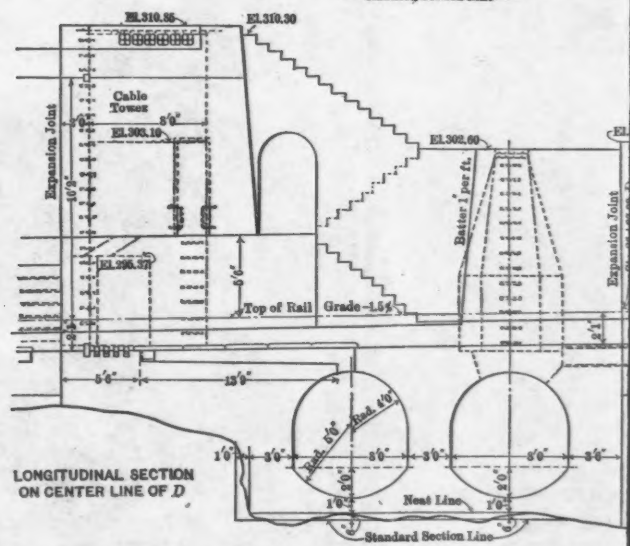
SECTION ON CENTER LINE OF EAST SUMP



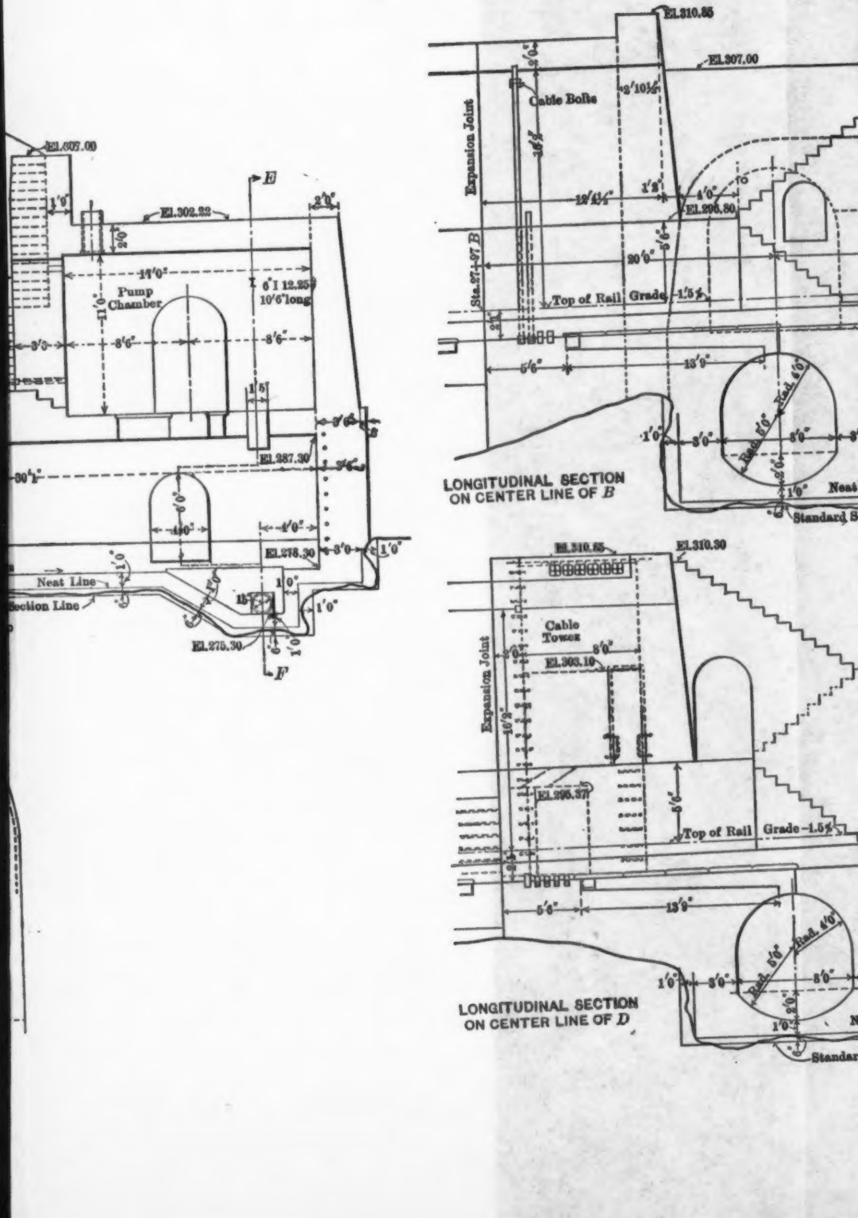
SECTION A-B



LONGITUDINAL SECTION ON CENTER LINE OF B



LONGITUDINAL SECTION ON CENTER LINE OF D



LONGITUDINAL SECTION ON CENTER LINE OF *B*

LONGITUDINAL SECTION ON CENTER LINE OF *D*

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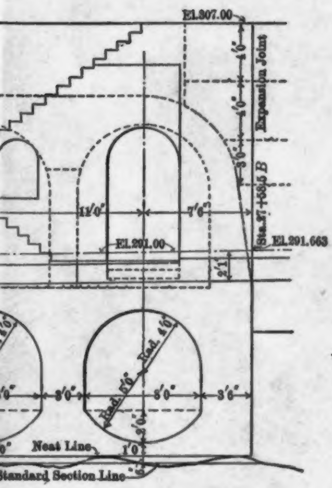
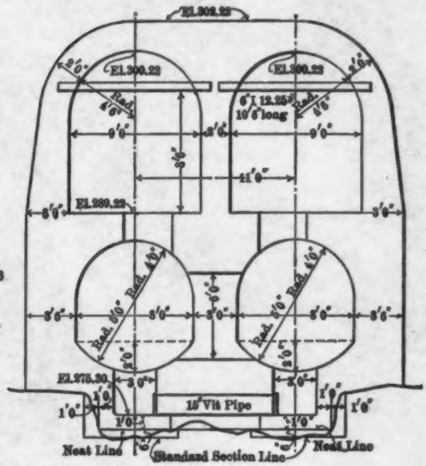
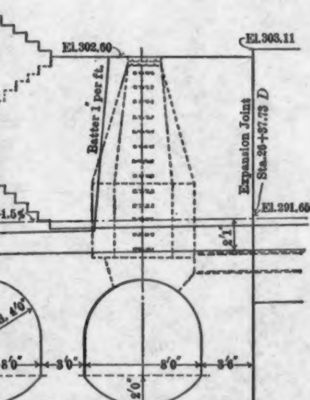




SECTION *E-F*



DETAILS OF PORTALS FOR TUNNELS *B* AND *D*

wet. Immediately overlying the rock, in practically all cases where it was uncovered 12 ft. or more below the surface, there was a water-bearing stratum of coarse sand and gravel, and there was ample evidence (of which one or two instances will be noted) that the same water-bearing stratum existed where the rock was not uncovered. On the line of *B-D* invert, near Station 19 (*D*), the borings were too far apart to give sufficient information as to depth of rock, and a 2-in. pipe was driven down at several points. At one of these points, it being found difficult to remove the pipe, it was allowed to remain, and water flowed from its top, the flow continuing even after the excavation for the invert was completed and until the pipe was finally removed. Many piles which were slightly heart-checked showed a small flow of water through the checks when the surrounding ground was 1 ft. or more below their tops, and, during cold weather, mounds of ice were frequently formed on tops of piles which would have been dry except for the water rising through them.

The strike of the rock was almost directly east and west, about at right angles to the general strike underlying the portion of the work in Manhattan. The pitch was generally about 90°, although varying greatly from that angle for short stretches.

The rock uncovered was a very good quality of gneiss, sometimes degenerating to mica schist, but for the greater part containing but little mica and in very minute particles, so that much of that excavated made an excellent concrete stone, about 1 cu. yd. of crushed stone being obtained for each yard of rock excavated.

Construction.

The first step taken by the contractors was to drain the area east of Hunter's Point Avenue. Two 4-in. centrifugal pumps, operated by a 40-h.p. boiler, were placed along the railroad near Court Street, and a main ditch was opened, parallel to the tracks, with cross-ditches leading from the ponds between the filled streets. The pumping plant began working on July 10th, 1907, discharging into Dutch Kills Creek over low ground lying south of Meadow Street, and in less than 24 hours had lowered the water to such an extent that only one pump at a time could be run. After one week's pumping very little water remained. Throughout the work no difficulty was caused by the surface-water, which looked quite formidable at the start, but pumping had to be con-

tinued for a few hours per day with the surface plant until the work was practically completed.

A comparison of Plates XXV and XXVIII will show that the Long Island Railroad tracks cut the work into two sections, and that in their position, shown on Plate XXVIII, they effectually prevented any work on a large part of the construction for and in the vicinity of Hunter's Point Avenue. As it was very desirable that the bridge on that avenue should be completed and the traffic restored to it as early as possible, a roadbed had been graded for the tracks on the line of Meadow Street, as shown on Plate XXV, previous to letting the contract. The moving of the tracks to that location required the cross-connection for freight near the outer end of the work, and made very desirable the completion of the abutment and four piers at the easterly end of Line 13, Plate XXV, before they were moved. The south abutment of Hunter's Point Avenue Bridge, the small piers just east of the *B-D* portal and the *B-D* invert itself were all so close to the proposed temporary location of those tracks that it was expedient to construct as much of them as possible while the tracks remained in their original location. This condition fixed four points of attack, the abutments and piers above mentioned forming three and the easterly end of the *B-D* invert the fourth, and, since 90% of the rock excavation lay west of Van Alst Avenue, it was likewise desirable to open up that end of the work at once, which made a fifth point of attack. The tracks were put in service in their temporary location on May 11th, 1908, the piers and abutments mentioned having been completed with the exception that only the foundations could be built for the two southerly piers of the group of four near the *B-D* portal because their location was immediately under that of the tracks. The easterly 400 ft. of the *B-D* invert was likewise completed at that date, and the work west of Van Alst Avenue well opened up.

For convenience in handling, the work was divided into three sections, and each was put in charge of a separate superintendent, the work west of Hunter's Point Avenue forming the first, Hunter's Point Avenue Bridge and the tunnels underneath the second, and all work east of Hunter's Point Avenue the third.

The excavation west of Van Alst Avenue was made in open cut, the earth being excavated by a small Thew steam shovel and disposed of by horses and wagons on the northerly approach to Hunter's Point

INVERT APPROACH TO *B* AND *D* TUNNELS.

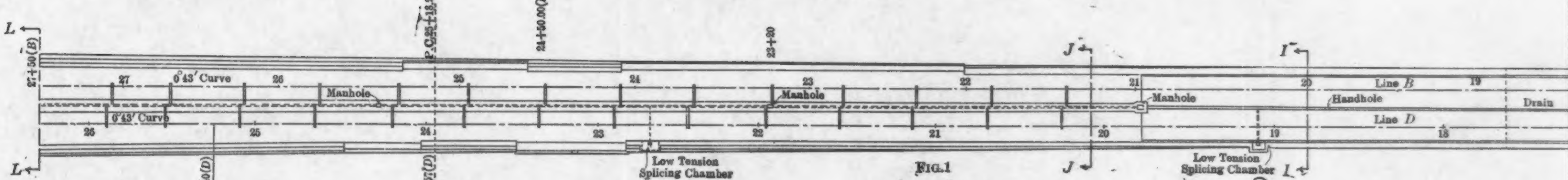


FIG. 1

GENERAL PLAN

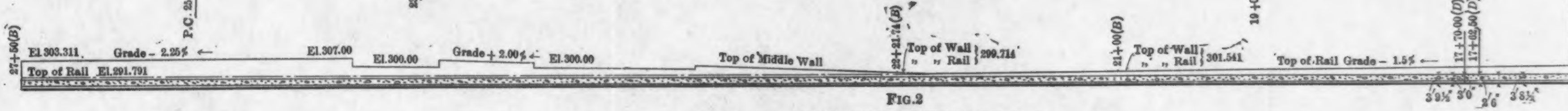


FIG. 2

ELEVATION OF MIDDLE WALL

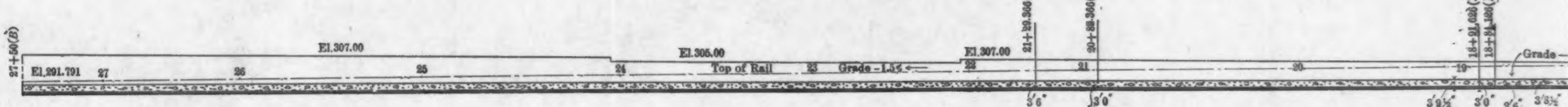


FIG. 3

ELEVATION OF NORTH WALL

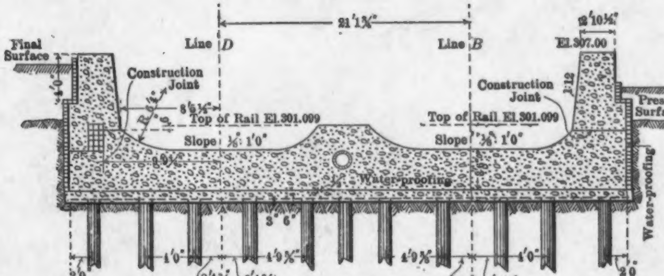


FIG. 4

SECTION *JJ* AT STA. 21 + 29.404 (*B*)

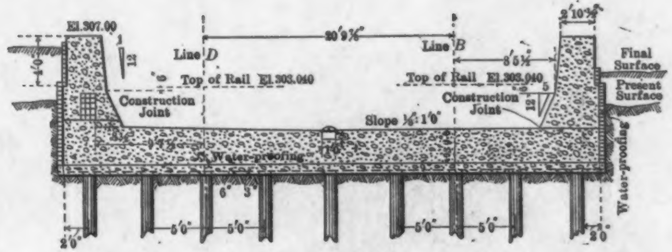


FIG. 5

SECTION *I-I* AT STA. 20 + 00 (*B*)

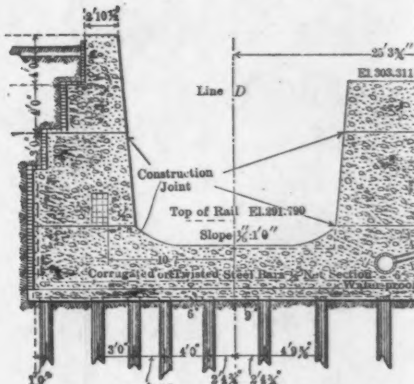


FIG. 6

SECTION *LL* AT STA. 2

INVERT APPROACH TO *B* AND *D* TUNNELS.

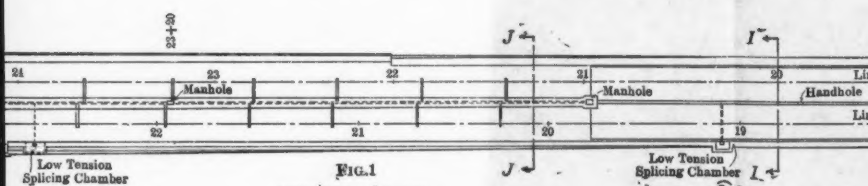


FIG. 1

GENERAL PLAN

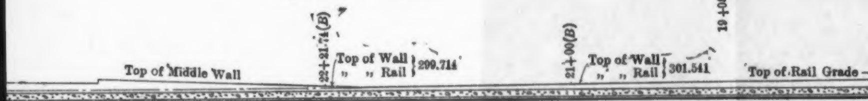


FIG. 2

ELEVATION OF MIDDLE WALL

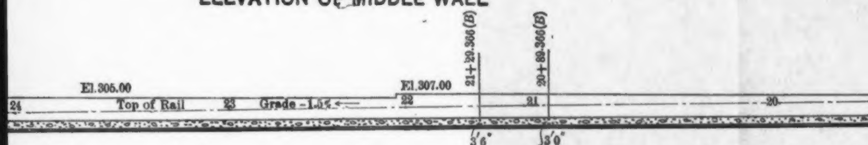


FIG. 3

ELEVATION OF NORTH WALL.

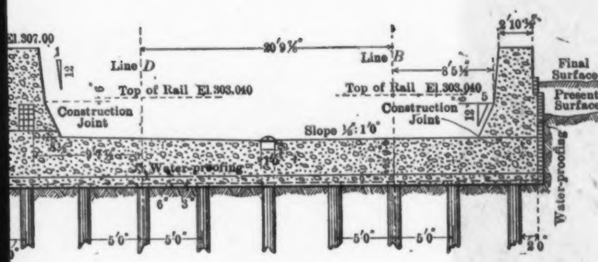


FIG. 5

SECTION *I-I* AT STA. 20 + 00(*B*)

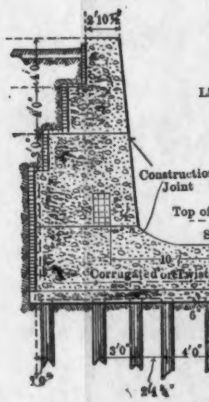


PLATE XXVII.
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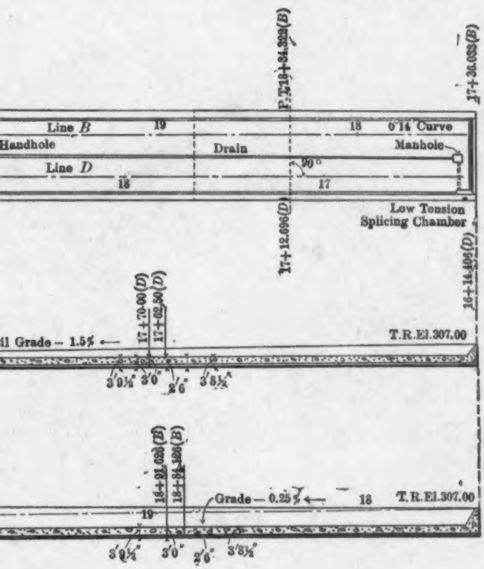


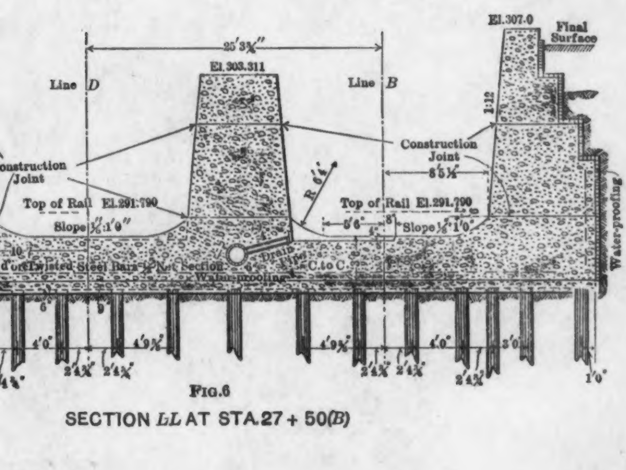


FIG.6
SECTION *LL* AT STA.27 + 50(*B*)

Avenue and adjoining streets, where the material was used to bring their grade up to a new level made necessary by the construction of the tunnels and the alterations in the Long Island Railroad. That portion of the approach to the old Hunter's Point Avenue Bridge which lay above the general surface and had to be removed by reason of the increased length of bridge, was likewise removed by steam shovel, but all excavation, with the two exceptions just noted, was made in securely-sheeted trenches. That for the *B-D* invert and Tunnels *B* and *D* east of Hunter's Point Avenue will be described somewhat in detail, as it was typical of the whole work, and variations from it will be noted.

Lines *B* and *D*, as previously explained, approach the tunnels in a common invert, shown on Plate XXVII, although for a part of the length the lines are separated by a concrete wall.

The excavation for the invert varied from 49 ft. wide at the easterly end to 69 ft. at the portals, and in depth from 8 ft. at the former point to 22 ft. at the latter.

A line of piles, 12 ft. apart, was driven on each side of the proposed permanent construction and about 2 ft. outside of it, with two additional lines set so as to divide the excavation into three approximately uniform widths, as shown by Fig. 1, Plate XXIX. To these piles the rangers and struts of the top set were bolted. The struts were 12 by 12-in. squared timbers, though in some of the later work round sticks were used. The top set of rangers was formed by two 8 by 12-in. sticks blocked apart sufficiently to form a slot for the sheeting, which varied in thickness from 4 to 6 in., depending on the depth of the excavation to be made. The piles described above were driven by a 2 000-lb. sheeting-hammer shown on Figs. 1 and 2, Plate XXIX.

The timbers were set in place and the piles were delivered to the driver either by derricks, as in Fig. 1, Plate XXIX, or by the travelers shown in the background on that photograph and at closer range on Fig. 1, Plate XXXII, in which the two travelers are standing back to back on their rails. All the derricks were supported on clusters of piles driven for the purpose, therefore, they could be erected very close to the side of the excavation, which gave them a greater effective radius than they would otherwise have had. Each traveler rail rested on short ties carried by two 12 by 12-in. stringers,

supported by three pile bents every 10 ft., the piles being driven by the steam hammers subsequently described. These piles were in proper locations for the finished work, and, after the excavation was completed, those which did not have a proper bearing were driven deeper by the 2 000-lb. drop-hammer, after which all were cut off at the correct elevation and used in the permanent work.

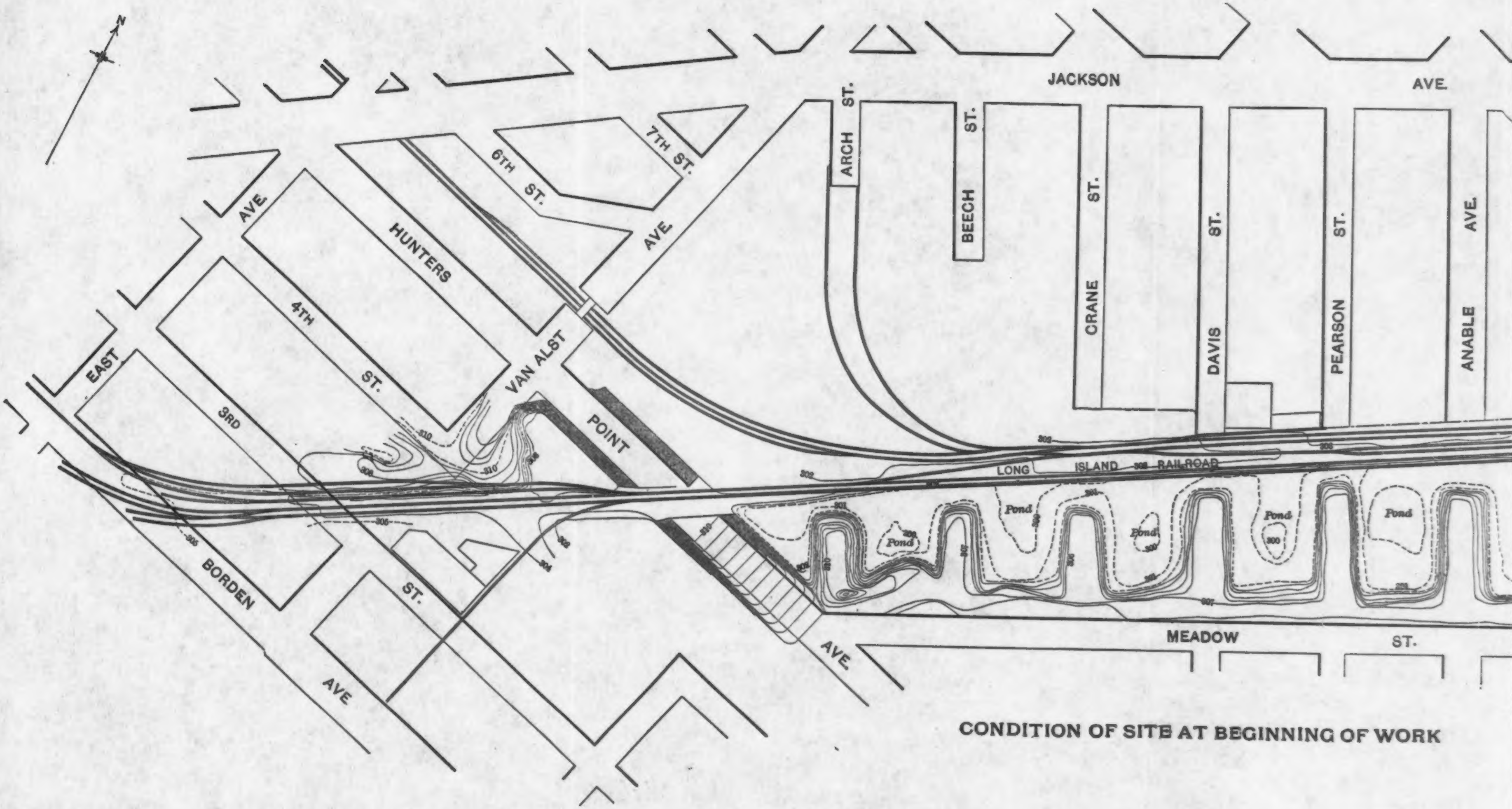
The sheeting was set up and driven by the sheeting drivers before mentioned, which were moved along on rollers resting on the top set of struts. It was driven, before beginning the excavation, as deep as it would go and yet remain plumb; this was, in some cases, the entire depth required, and, in all other cases, through the swamp mud and into the underlying material. The use of heavy sheeting was of great advantage, on account of its ability to stand the driving and to span considerable lengths when it became necessary to remove struts during the concreting.

As previously stated, the entire *B-D* invert rested on a pile foundation, the bents being 5 ft. apart and the number of piles per bent varying from 9 to 15. For the easternmost 460 ft., where the depth of excavation was small and the material to be excavated of such nature that its presence at the time of driving would not affect the penetration, the piles were driven before excavating was commenced.

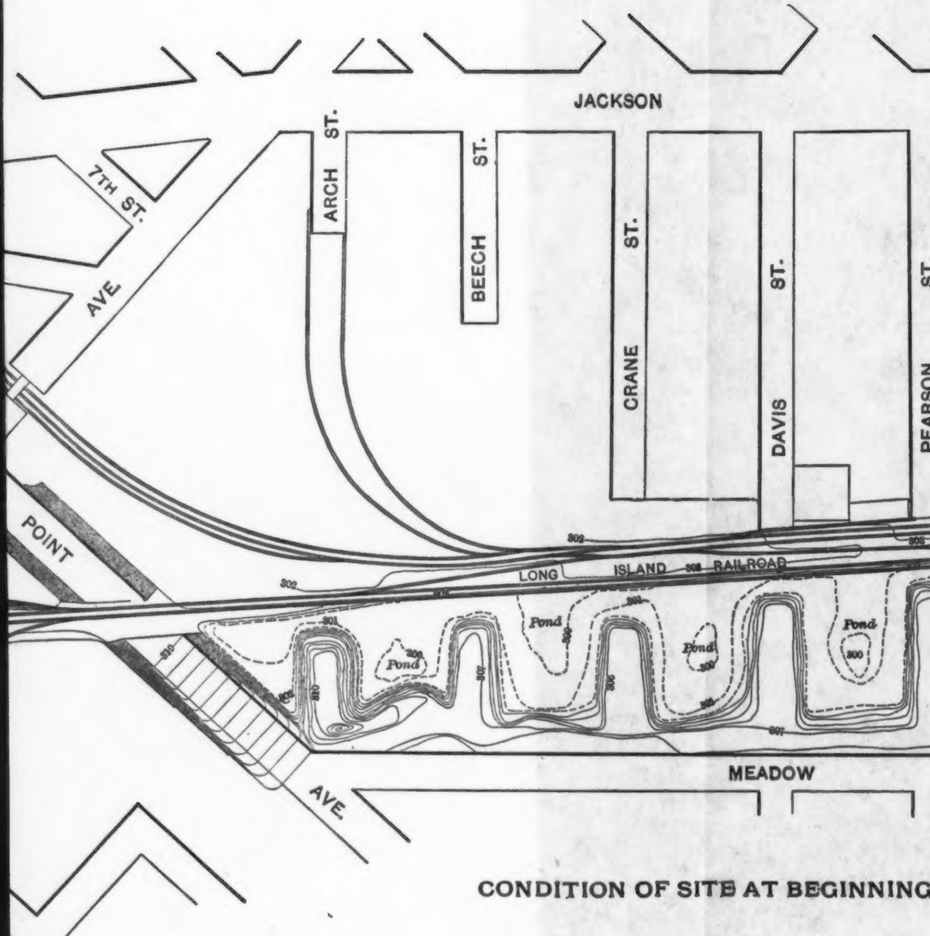
The excavating was done by ½-yd. and 1-yd. orange-peel buckets operated by the derricks or travelers, a few men being kept in the trench to shovel the material from under the struts and rangers to points where the buckets could reach it. The material was loaded into narrow-gauge dump-cars and such of it as was suitable was deposited in embankment for surface tracks or used for back-filling completed structures, while the swamp mud was wasted on low ground south of Meadow Street.

Additional sets of struts and rangers were placed at intervals of from 6 to 4 ft. as the excavation proceeded, the latter spacing being used toward the bottoms of the deeper portion of the trench.

Where the bottom, at the elevation of the base of the concrete, was so soft that it would churn up and become mixed with the concrete in placing, the excavation was carried from 1 to 4 ft. deeper, and the intervening space was filled with refuse from the rock excavation and dust from the crusher. The greater depth was used at all points where the excavation had not penetrated the swamp mud and was sufficient



CONDITION OF SITE AT BEGINNING OF WORK



CONDITION OF SITE AT BEGINNING

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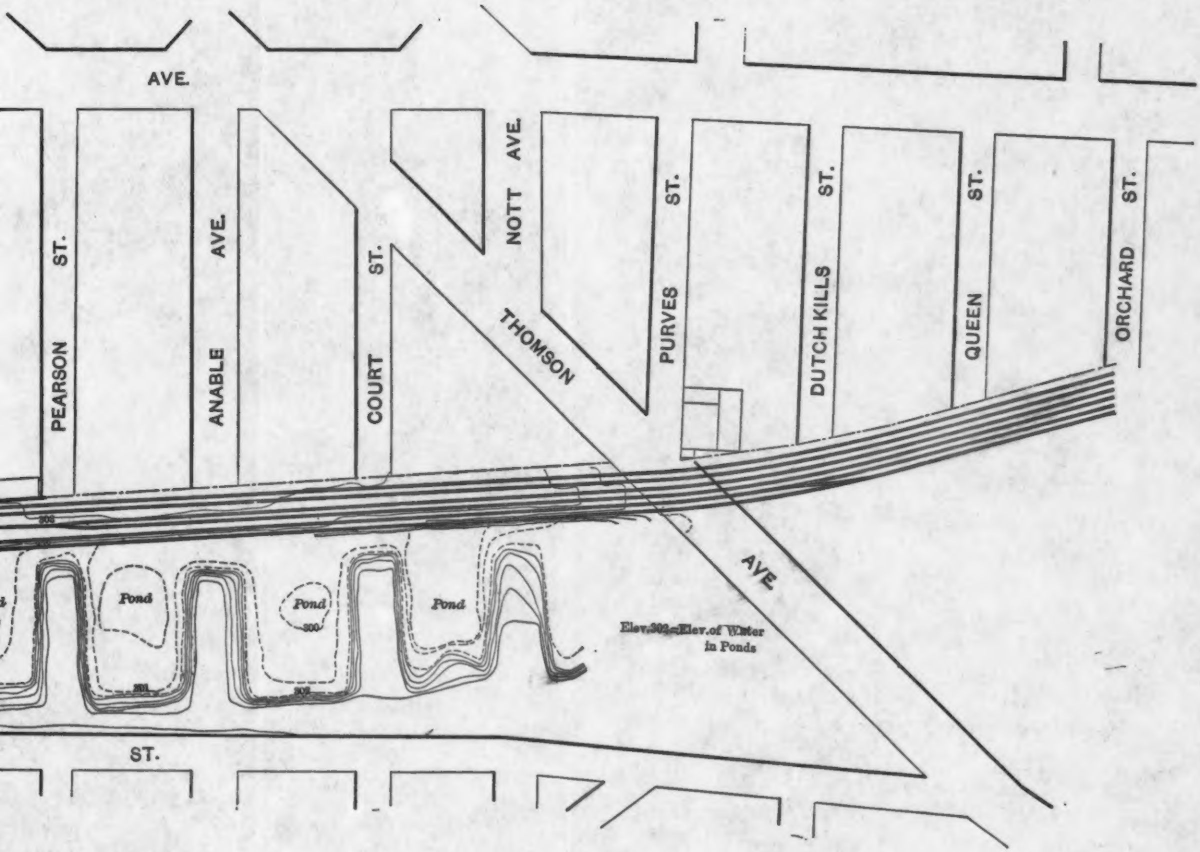


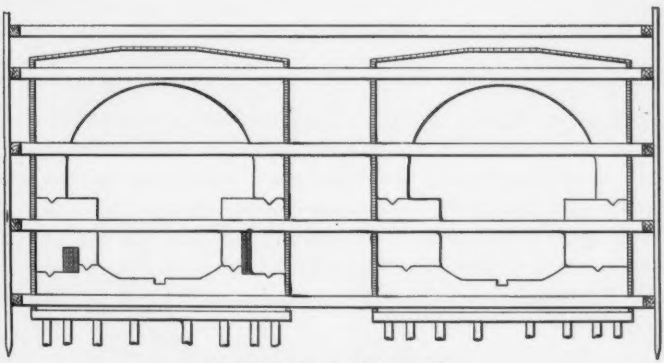
NING OF WORK

to form a blanket through which the mud did not work previous to the concrete being placed.

B and *D* Tunnels West of Portal.

Although the two tunnels were built separately throughout most of the distance from the portal section to Hunter's Point Avenue, they were constructed in a single trench, the distance between them being so slight as to make the removal of the additional excavation less expensive than the driving of two lines of sheeting. The width of the trench varied from 57 to 67 ft., and the depth from 17 to 37 ft.

The methods of sheeting and excavating were similar to those described above for the invert, except that the travelers were not used,



ARRANGEMENT OF STRUTS.

Fig. 4.

all the excavation being made by the derricks which, on account of the width of the trench, were alternated on its two sides.

The struts in all trenches for tunnels were placed at such elevations as would require the least number possible to be removed at each step of the construction, as shown on Fig. 4.

The entire excavation for Tunnels *B* and *D* was carried to a depth considerably below the bottom of the swamp mud, and much of it was carried to rock through material so firm as to require picking, after which, however, it was loaded into cars by the orange-peel buckets before described.

PORTAL SECTION.

The construction of the *B-D* portal was commenced at about the same time, and was carried on simultaneously with that for the invert. The excavation was somewhat wider than that for either tunnels or invert, the additional room being required for the pump chamber and sump, and, as it was intended to complete the portals to the top of the tunnel bench before proceeding with the excavation east or west of them, it was sheeted on all four sides, and the timbering varied considerably from that described for the invert, as shown by Fig. 2, Plate XXIX. The framing was done in rectangular 10 by 12-ft. bays of 12 by 12-in. timbers, and the sheeting was 8 by 14-in. with a tongue and groove formed of $1\frac{1}{2}$ by $2\frac{1}{2}$-in. strips firmly spiked to the main timbers.

The location of the portals brought a part of the excavation within the limits of the fill for Crane Street. This was removed to the general level of the swamp, the rangers and struts of the top set were then placed and temporary piles for supporting them were driven at each intersection, as shown by Fig. 2, Plate XXIX, after which the sheeting was set and driven through the swamp mud. Excavation was then commenced with one of the orange-peel buckets operated by a derrick. Fig. 2, Plate XXIX, gives a good idea of the nature of the material and the length of sheeting remaining to be driven during the excavating. Additional tiers of struts and rangers were set at intervals of about 5 ft.

The effect of continuing to drive piles after they have reached rock was clearly shown when the earth excavation for these portals was completed. Piles were furnished the timber foreman in charge of this excavation, of a length somewhat greater than necessary to reach rock at the elevation indicated by the borings, and he was instructed by the superintendent of the work to drive them to rock. The machine used was one of the 2 000-lb. sheeting-hammers before mentioned. The foreman reported that he had driven the piles as far as possible without bringing their tops below the upper set of timbers which they were intended to support and had not reached rock, which must be deeper than anticipated. Figs. 1 and 2, Plate XXX, show what actually occurred, the bottoms of practically all the piles being similar to those here shown, and a glance at Fig. 2, Plate XXIX, will show that the

PLATE XXIX.
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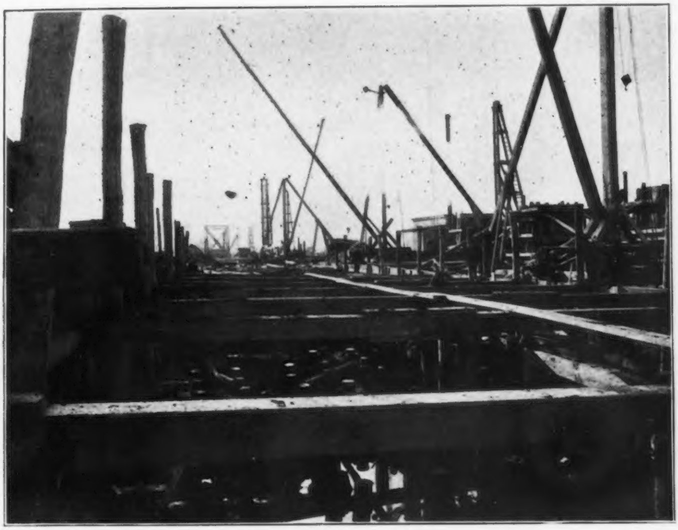


FIG. 1.—TIMBERING OF *B-D* INVERT.

FIG. 2.—TIMBERING FOR *B-D* PORTAL.

tops were not badly broomed. Unfortunately, no record was made of the amount or rate of penetration of these piles or of their actual length before driving, as they were not a part of the permanent work, but the foreman insisted that they all moved very uniformly up to the time he stopped driving.

LINE *A* INVERT AND TUNNEL.

The excavation for Line *A* invert and tunnel east of Hunter's Point Avenue was very similar to that described for *B-D,* with the exception that, being for a single line, it was much narrower, 30 ft. at the easterly end and 44 ft. at the widest point.

HUNTER'S POINT AVENUE VIADUCT.

The excavation for Hunter's Point Avenue Viaduct and the tunnels underneath was made in four trenches. Trench No. 1 was for the south abutment alone, and was 196 ft. long, 30 ft. wide, and varied in depth from 16 to 30 ft. The timbering was similar to that described for the *B-D* invert, the top set being shown by Fig. 1, Plate XXXIII, together with the location of two stiff-leg derricks which covered the entire excavation. Excavation No. 2, in the order in which they were made, was for Tunnel *A* and the north abutment, the two structures being a continuous block of concrete, although not a monolith from foundation to bridge seat. This excavation was 176 ft. long, 51 ft. wide at all points, except for the wings of the abutment, and the depth from the general surface to rock was from 18 to 44 ft., which, except at the extreme easterly end, was above the proper elevation for the foundation of the tunnel, and, therefore, required that the rock be excavated for the width of the tunnel and for a depth varying from 0 to 9 ft.

There was a slight variation from the general method in the procedure at this excavation, due to the site being partly occupied by the northerly abutment of the old overhead bridge previously mentioned. It was founded on piles about 3 ft. below the level of the general surface, and was removed and the entire excavation made to that depth before any timbering was placed. Two sets of rangers and struts were then laid, the first on the bottom as excavated, and the second posted 5 ft. above, after which the sheeting was set and driven about 5 ft. below the lower set of rangers and carried down as the excavation proceeded.

The third excavation was 142 ft. long and 58 ft. wide, and included the three southerly piers and Tunnels *B* and *D*. The fourth excavation, for the northerly pier and Line *C* invert, was shallow, as the foundation was on piles at an elevation of only 8 ft. below the general surface, and was made between the southerly sheeting of Trench No. 2 and the northerly sheeting of Trench No. 3.

Concreting.

In building concrete the following general principles were adhered to: that all concrete sections for piers and abutments should be monoliths above the level of the surrounding grade; that tunnels and inverts should be monolithic as nearly as practicable; and that the length of sections in continuous structures should be approximately 50 ft.

Sequence of Operations.

On all invert work resting on piles, three concreting operations were necessary; the first was the concrete base for water-proofing, which was 9 in. thick, 3 in. about the heads of the piles and 6 in. over them; the second comprised the floor from the water-proofed base to the elevation of the bottom duct; the third was the construction of the side-walls. For 346 ft. of the westerly portion of *B-D* invert, where the distance from the bottom duct to the surface of the ground was greater than 11 ft., it was not considered safe to remove all struts, and the side-walls were built in two lifts, making a total of four operations. The limits of these several operations are shown on Plate XXVII by lines marked "construction joints."

The tunnels were built in three operations above the rock foundation, or water-proofing, where not founded on rock; the first was the floor and side-walls up to the level of the ducts; the second was the bench-walls; the third was the arch. In the north abutment for Hunter's Point Avenue Bridge, built in conjunction with Tunnel *A*, these levels were carried right through the abutment, and the final lift, above the top of the tunnel arch, was built as a monolith. At the crossing of Tunnel *C* over Tunnel *B*, west of Hunter's Point Avenue, the third operation of Tunnel *B*, namely, the arch, included the floor of *C* up to the duct level, leaving two operations for Tunnel *C* proper, and making five for the two tunnels. These "construction joints" are shown on Figs. 1, 2, and 3.

FIG. 1.—PILES, SHOWING RESULT OF TOO MUCH DRIVING.

FIG. 2.—PILES, SHOWING RESULT OF TOO MUCH DRIVING.

The forms for the first lift, or water-proofing base, were very simple, consisting of a 10-in. plank along each side, braced from the sheeting so as to form a ditch for carrying off the water, and a bulkhead of the same height at the end of the section. Steel rods, of ½ sq. in. net section, were then placed resting directly on the piles, longitudinally, crosswise, and on both diagonals. These rods were intended to bind the entire mass together and prevent the piles from pulling the slab apart if subjected to lateral pressure from mud waves.

The concrete was delivered in 2-yd. Stuebner buckets, handled by derricks and dumped by laborers standing on the prepared foundation, no handling of the concrete being necessary after it was dumped, excepting ramming and spading about the piles and steel rods. A surface sufficiently smooth for the water-proofing was obtained by patting the concrete with the flat of the shovel; where an occasional point of stone showed through, after the base had hardened, it was picked out and the void filled with mortar.

The next step was to build the brick protecting wall for the water-proofing to a height at least up to the level of the duct bench. Where necessary to make room, as was the case in the section shown by Fig. 1, Plate XXXI, the lowest set of timbers was first removed, the thrust being taken by the 9-in. water-proofing base.

Forms for supporting the brick wall were built in sections, from 12 to 20 ft. long and from 4 to 6 ft. wide, of 2-in. planking securely spiked to 4 by 6-in. posts, and were easily swung about from place to place by the derricks and quickly set up and braced to the sheeting. They are shown extending slightly beyond the brick wall in Fig. 1, Plate XXXI. The brick wall was 4 in. thick, and a fillet of mortar was formed at the junction with the concrete base, as it was found impossible to tuck the water-proofing into an absolutely square corner and keep it there.

The water-proofing, of six ply of felt and seven of pitch, similar to that described in previous papers of this series, was applied in two sheets of three layers each and in three lengths. The first sheet of three layers was laid on the base extending from brick wall to brick wall, as shown by Fig. 1, Plate XXXI, each strip lapping 2 ft. over the previous strip. A sheet of three layers was then applied to each brick wall, the strips running vertically and breaking joints in a manner similar to those in the base sheet, over which it lapped at

least 1 ft. The second sheet of three layers was then laid on the base, lapping 1 ft. over the ends of the vertical strips, and was followed with the sheet of three additional layers on the brick walls, laid as before described.

It can be noted by referring to the "construction joints" shown on Figs. 1, 2, and 3, and Plate XXVII, that the floor sections, as built, included the side-walls up to the duct-bench for plain floors, and for floors with fillet included the entire fillet, which extended from 0 to 9 in. above the level of the bottom ducts, and necessitated a step down, of that amount, just in front of their location.

The forms for the few inches of side-wall built in conjunction with the plain floor consisted simply of a square timber with one side cut to form the batter of the wall. The forms for the fillet were built up in 26-ft. lengths, so that two lengths would serve for one side of a 50-ft. section and lap on the finished work. These forms are shown by Fig. 5. They were supported at one end on the finished work, at the other on the timber bulkhead at the end of the section and at four or five intermediate points on concrete pillars previously moulded for the purpose, and indicated in dotted lines on Fig. 5, and were further held in position by vertical and diagonal braces from both sides of the forms to the struts above. The drain form, likewise shown on Fig 5, was similarly supported. Each section contained two large iron rings by which it could be lifted vertically by the derricks. In that portion of the *B-D* invert having a center-wall, four lines of the fillet forms were necessarily required. The drain, a 15-in. vitrified pipe in the floor under the center-wall, was laid as the concrete was placed, and wired up to and braced down from the struts above. Fig. 2, Plate XXXI, shows the first section of invert floor of this type built. At the time this photograph was taken the fillet forms had been removed and are seen lying loose, the section had been back-filled up to the level of the duct-bench and the top set of timbers had been removed preparatory to moving the side-wall forms ahead. These forms are seen in the background, where the preceding section of side-wall is being concreted. These forms and those for the bench-walls of the tunnels were very similar, those for the tunnels being shown by Fig. 6. They were very solidly constructed, and the bolts and wedges (shown by Fig. 6) permitted their adjustment to the curves to a nicety, and enabled them to be slacked off readily for moving

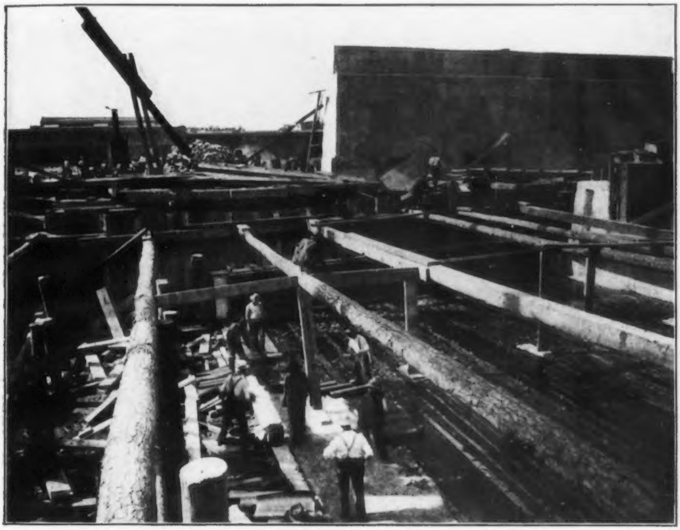
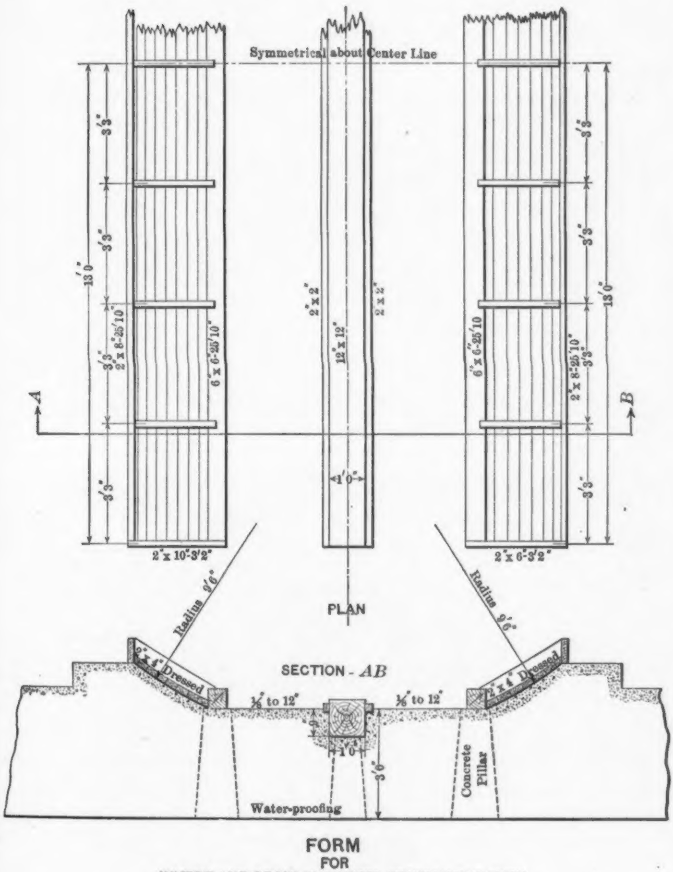


FIG. 1.—*B-D* INVERT. SHOWING WATER-PROOFING.

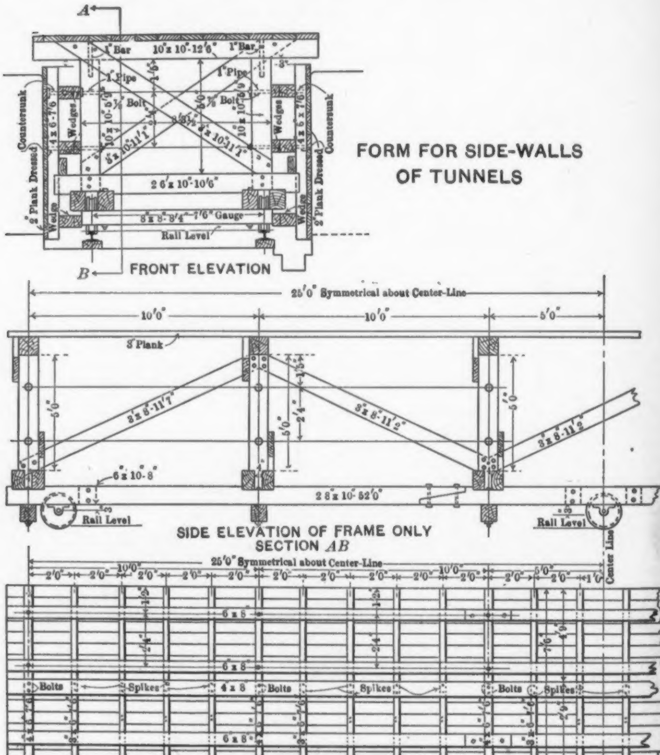
FIG. 2.—*B-D* INVERT, SHOWING FLOOR SECTION AND FORMS.



FORM
FOR
INVERT AND DRAIN IN TUNNEL SECTION IN EARTH

Fig. 5.

ahead from section to section. They were built in 52-ft. lengths, so that one end was constantly engaged by the finished work. They traveled on 70-lb. rails laid on stringers on the floor of the tunnel, being pulled ahead by a block and fall operated by one of the derricks, and, when in position for concreting, were blocked free of the rail.



SIDE ELEVATION OF FORM ONLY
SECTION *AB*
FIG. 6.

The outside forms were similar to those described for the invert floor, and were used for the tunnels in earth in the same manner, being set up outside the line for the brick protection which was then built and water-proofed before the concrete was placed. For the in-

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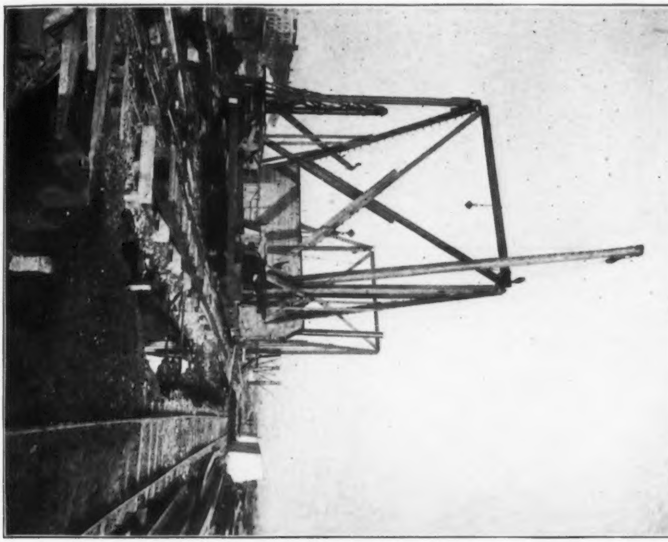

FIG. 1.—TRAVELER USED ON *B-D* INVERT.

FIG. 2.—FORMS FOR CONCRETE APPROACH TO OVERHEAD TRACK BRIDGE.

verts, the back forms above the duct-bench were set on the line of the back of the concrete, and the water-proofing and brickwork were placed subsequently. This was necessarily so, as the backs of the inverts stepped in at each 4 ft. of rise, and the brickwork above the first step had nothing on which to rest until after the concrete was built.

The ducts for electric cables were sometimes laid before the bench-wall forms were moved ahead, and sometimes afterward, but were in all cases allowed to set before the concrete was deposited about them.

The arrangement of the ducts is shown by Figs. 1, and 2. They were of only two kinds, low-tension, and telephone and telegraph, the former being single and the latter four-ways. The ducts themselves and the methods of laying have been described in previous papers of this series.

The concrete was delivered in Stuebner buckets by the derricks, as described for the floor, but was dumped, not in the form, but on the platform over the carriage, and shoveled from there into the form, care being required to keep it at all times at the same level at the back and in front of the ducts, as they were easily pushed out of line. This was particularly true of the four-ways which stood in a single tier six high. Two men in each bench-wall kept the concrete well rammed and spaded. After the ducts were covered, the concrete was dumped directly into the forms, and little shoveling was necessary.

The arch forms were built in sections of the same length as, and supported on, though not attached to, carriages similar to the bench-wall forms. The carriage and forms are shown by Fig. 7. The ribs, 4 ft. 6 in. from center to center, were made of two 5 by 3 by $\frac{3}{8}$-in. angle irons, placed back to back and separated sufficiently to admit the braces. They were hinged at a point 3 ft. $3\frac{1}{4}$ in. above the springing line of the arch, which was itself 2 ft. $8\frac{1}{4}$ in. above the bench, and the end sections of the bottom chord, being hinged at the junction with the arch rib and bolted at the inner end, could be removed and the whole lower section of the form pulled into the position shown in dotted lines on Fig. 7 when it was desired to slack the arch.

The arch ribs rested on and were securely bolted to 8 by 12-in. timbers laid flat and parallel to a 50-ft. chord of the tunnel curve, the arch ribs being radial, with their ends parallel to the curve. The sheeting was of $2\frac{1}{2}$ by 4-in. yellow pine, cut to the curve of the

intrados, with radial edges, and was bolted with stove-bolts to the arch ribs. The forms were blocked into position with wedges between the longitudinal timbers mentioned above and similar timbers bolted to the top of the carriage, and also from blocking resting on the bench-walls near the outer ends of the lower chords.

The most economical procedure was to have a sufficient length of floor concreted ahead of bench, and of bench ahead of arch, to enable the forms to be moved in their regular order, but the room for receiving excavated material was so limited that at times it became expedient to carry the arch even with the completed bench; in which case the arch forms were run ahead on pipe rollers and blocked up on the platform of the bench-wall carriage. The bench-wall carriage was pulled ahead for the next section of bench when desired, the arch form being left blocked up on the completed bench-wall, and its own carriage was shoved under it for the subsequent move.

The outside forms above the bench, for tunnels in earth, were similar to those described for the floor and bench-wall, but were built in sections of the same height as the vertical height of the tunnel above the bench-wall.

The concrete was dumped from the buckets before described on the crown of the arch form and with little assistance slid into position, where it was rammed and spaded into a compact mass by two men on each side of the arch. After the concrete had reached the crown of the arch, the buckets were dumped at different points over the entire section, and shoveling was thus avoided.

Tunnels in Rock.

The construction of tunnels in or on rock varied somewhat from that described for tunnels in earth, the amount of variation depending on the elevation of the original surface of the rock with reference to the floor of the tunnel. The variations, however, can be classed under three headings: tunnels resting on rock, but not in rock excavation; tunnels built in rock excavation, the original surface of which was below a line 5 ft. above the bench-wall; and tunnels in rock excavation, the original surface of which was above that line.

For tunnels resting on rock foundation, but not in rock excavation, the various steps were the same as for tunnels on pile foundations, except that, as the floor was not water-proofed, no sub-floor

FIG. 1.—SOUTH ABUTMENT OF HUNTER'S POINT AVE. BRIDGE. SHOWING FRAMING OF TOP SET OF TIMBERS.

FIG. 2.—TUNNELS *A* AND *B* IN ROCK, SHOWING BENCH-WALL FORMS AND WATER-PROOFING.

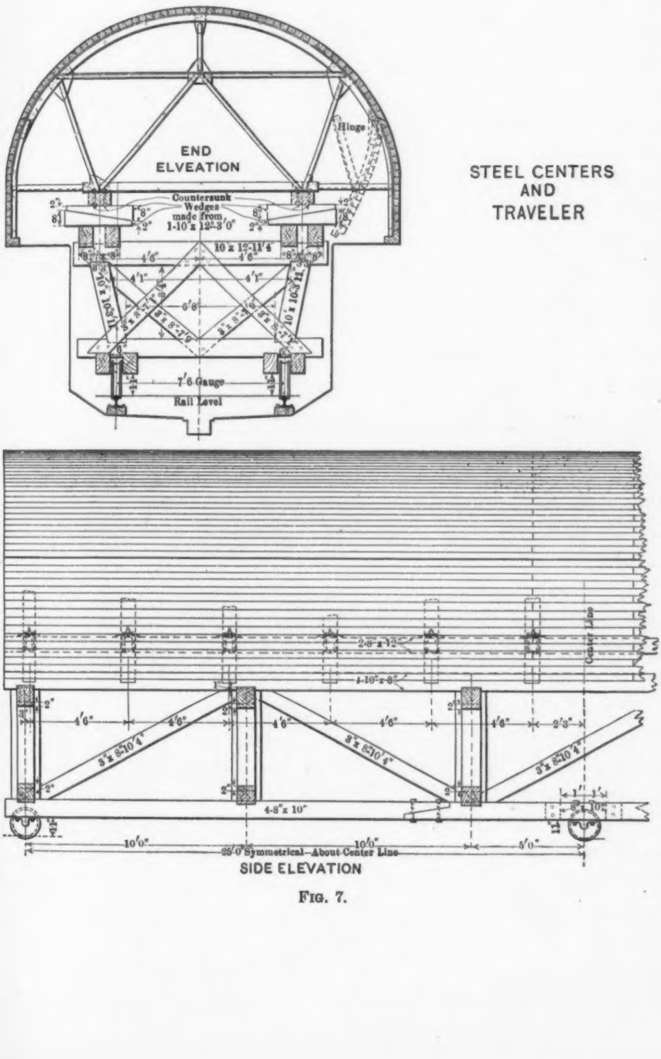
END
ELVEATION
STEEL CENTERS
AND
TRAVELER
Hinge
Countersunk
Wedges
made from
1-10"x 12"-3'0"
10"x 12"-11'4"
7'6 Gauge
Rail Level
Center Line
4-8"x 10"
25'0" Symmetrical-About Center Line
SIDE ELEVATION

FIG. 7.

was required, and the first operation was the building of the brick protecting walls for the water-proofing of the benches. In some cases where the rock, on which the tunnels were to rest, was more than 2 ft. below the finished floor, concrete was deposited up to that level before the brick walls were started. When the water-proofing was placed on the brick protecting walls, it was carried down to their base, and, as the concrete for the floor proper was being deposited, the bottom 6 in. of the entire six laps was turned up and the concrete rammed in under and about it, thus forming a seal to prevent water from rising between the concrete and the water-proofing and finding a joint through which to work into the tunnel.

Where tunnels were in rock excavation, the first step was to build sand-walls of concrete, filling the entire space between the water-proofing line and the sides of the rock excavation. Where the surface of the rock was below the level of the top of the bench, the sand-walls were built for the full height at one operation, but, where the rock was high, two or more operations were required, as it was difficult to force the concrete down so narrow a space, if of considerable height, the sand-walls varying in thickness from practically nothing to 3 ft., and also because it was difficult to attach the water-proofing to a sheer height and keep it there for the length of time that must elapse between the beginning of the construction of the floor and the completion of the arch.

The forms for the sand-walls were the same as those used for the brick protecting walls, and were held in place by raker braces from the bottom of the cut, or, for the upper lifts, from the completed bench-walls.

Fig. 2, Plate XXXIII, shows Tunnels *A* and *B*, with sand-walls on the south side of *B* and the north side of *A*, and brick protecting walls on the adjacent sides of the two tunnels. It can be noted that the water-proofing on the brick walls is tacked to the forms above the brickwork to prevent it from slipping; the strips of wood shown on top of the water-proofing on the sand-wall are for the same purpose, these being tacked through the water-proofing to similar strips which were embedded in the concrete when the wall was cast. When it was desired to continue the sand-walls or brick protecting walls higher, the strips were pulled off, and the loose laps of water-proofing were laid back on the finished bench-walls, and after the additional height

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FIG. 1.—TUNNELS *A* AND *B* IN ROCK, SHOWING ARCH FORMS.

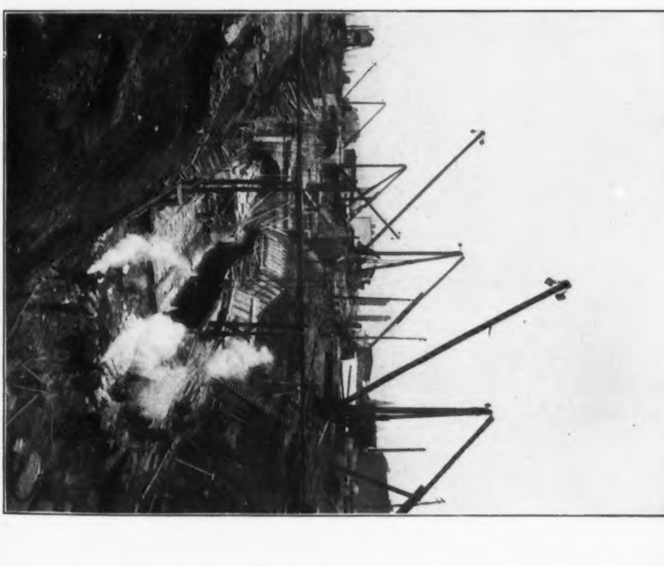

FIG. 2.—TUNNEL *C* CROSSING TUNNEL *B*,

of wall had been constructed, one sheet of three thicknesses of the water-proofing was then attached to the new wall. The first sheet of three thicknesses of the upper lift having been brought down and lapped over them, the remaining laps from the lower lift were raised and pitched to the wall, and the last three thicknesses from the upper lift were then applied. It was found very difficult to prevent the lower sheets from sagging after this had been done, particularly in warm weather, although they were braced as soon as possible after the operation was completed, and, during the later stages of the work, better results were obtained by cutting the water-proofing off just back of the strips, allowing the strips and the water-proofing under them to remain and be concreted in with the next lift of sand-wall and lapping the entire six-ply from the upper lift 1 ft. over the joint. This, of course, could not be done with the brick walls, and bracing had to be depended on to hold the water-proofing in place, which, however, was not a serious matter, as the brick walls, usually, were not continued until after the arch forms were in place, so that concreting followed promptly the application of the upper lift of water-proofing.

The greatest variation, from the forms and methods used for tunnels in earth, occurred where the rock was of sufficient height to form abutments and develop arch action in the tunnel, and its roof was a true arch section, as shown on Section No. 1 of Fig. 1. The forms for this type of arch were similar to those previously described, with the exception of the outer forms for the arch proper. These forms are shown by Fig. 1, Plate XXXIV, the form on the left being ready for concrete and that on the right in process of construction. Each bent, though securely bolted together, was little more than a template, and was not depended on to take the thrust from the wet concrete, the forms being firmly braced from the sides of the cut or adjoining arch. When being moved, the sheathing was knocked loose from the bents, and they were moved ahead and set up separately, after which the sheathing was replaced to the height shown in the photograph, about level with the intrados of the arch at its crown, the remainder being placed just ahead of the concrete, so as not to curtail the working space.

The crossing of Tunnel *C* over Tunnel *B* introduced special sections and therefore required special forms. Where the tunnels approached each other from the west and Tunnel *B* was entirely in rock

excavation and Tunnel *C* either required rock excavation or a slight thickening of the floor to reach the rock foundation, the special form work was slight. Fig. 1, Plate XXXV, shows the arch of Tunnel *B* and the floor of Tunnel *C* at the most westerly joint section, together with a sub-base for the next easterly section of Tunnel *C* built in conjunction with the southerly sand-wall for Tunnel *B*.

The special forms required where Tunnel *C* leaves Tunnel *B* on the north are clearly shown on Fig. 2, Plate XXXV, they being completed ready for concrete, as is the arch form for Tunnel *B*, the top of which shows in the foreground. The forms for the jack-arches were built in position and ripped apart at each move, 5 by 7-ft. openings being left between them, through which the material could be passed ahead. The rock underlying Line C at this point varied from 3 to 14 ft. above the base of Tunnel *B*, and the construction of the floor and side-walls of the latter was identical with that of the single tunnel, the entire jack-arch construction and the floor of Tunnel *C* being concreted with the arch of Tunnel *B*. Fig. 2, Plate XXXIV, shows the relative position of the tunnels just west of the jack-arch construction, the rock on which the jack-arches rested being shown to the right of the uncompleted portion of Tunnel *B*.

The cellular construction extended to within 97 ft. of the portal, from which point to the portal the viaduct support, mentioned in the description of the design, was used. In this construction the arches were built separately from the floor of the tunnel, and formed a sub-base on which water-proofing was laid similar to that described for tunnels on pile foundations, the entire construction varying from that of a tunnel on piles only in the substitution of the concrete viaduct for the piles.

The portals of the tunnels, although very simple in appearance when completed (as shown on Fig. 1, Plate XXXVI), required an immense amount of carpenter work, as can be readily seen by an examination of Plate XXVI, showing a few sections of *B-D* portal, which, on account of the two tunnels, is somewhat more complicated than that for either Tunnels *A* or *C*. This portal section was 38.5 ft. long, and included: a length of 14 ft. of tunnel, measured at the elevation of top of rail, the face of the portal being on a batter of 1 in. to the foot; 24.5 ft. of invert; three sets of stairs, each joining

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FIG. 1.—TUNNEL *C* CROSSING TUNNEL *B*: WEST END.

FIG. 2.—TUNNEL *C* CROSSING TUNNEL *B*: EAST END.

the roof of the tunnel, the top of the invert wall, the tunnel bench-wall, and the floor of tunnels; two sumps of arch and invert form, 8 ft. wide, 9 ft. high, and 63 ft. long; two 9 by 17-ft. pump chambers; one large manhole at the outlet of the drain to the sump; two splicing chambers; one telephone tower, for bringing the cables to the surface; and numerous openings for pump suction and discharge pipes, cables, etc.

The concrete was placed in four operations, the first including all concrete below the level of the duct-bench, the second the tunnel-bench and the steps leading from that bench to the tunnel floor, the third including the side-walls of the inverts, all remaining stairs, and the pump chambers above the floor, at which stage the photograph, Fig. 2, Plate XXXVI, was taken, and the fourth the tunnel arch.

The details of the form work would be of little interest, but a few points will be mentioned. The sump forms were built in sections at the contractors' shop, and required only to be joined together after being lowered into the excavation, where they were supported on bolts which had been concreted into the rock floor. They were prevented from moving sidewise, by being braced apart and from the sides of the excavation, which braces were removed as the concreting proceeded; and from rising by being filled with water above the level of the concrete as it advanced. The stair forms as first erected consisted of risers only, the treads being placed after the riser was full of concrete. The arch roof of the portal was not built until after the bench-wall to the west had been completed and the regular tunnel centers had been erected.

Care of Spring-Water.

Many springs were encountered in the rock excavations, and, as the water had considerable head, great care was required to handle it so as to prevent it from washing the cement out of the concrete floors and leaving them porous. The usual method was to build a small brick inverted sump over the spring and lead it through a pipe (which was concreted in) to some point outside the section. One of the largest springs was in the last section to be concreted in Tunnel *B*, near Station 36 + 60. The usual methods were tried, but, probably due to this being the last section, which required the water to rise in the pipe slightly above the level of the finished floor before it could run off, there were three springs through the floor of the concrete

after it had set. The porous concrete was cut out about these points, and pipes were set and grouted in the floor, the flow being thus confined to the pipes. After the grouting had thoroughly set, the pipes were plugged temporarily, but this was followed by leakage from the expansion joints on either side of them. The leakage formed quite a stream at several points below the level of the bench-wall and at the bench-wall, and in one of the joints produced moisture as high as the crown of the arch. When the plugs were removed from the pipes, the leakage at the expansion joints subsided and finally ceased entirely. The flow from these three pipes, aggregating about 5 000 gal. of water in 24 hours, is allowed to find its way to the sumps through the drains provided for that purpose.

It was found in a number of instances that the seal before described at the bottom of the side-wall water-proofing was not quite effective, and small streams of water were discovered rising to the level of the duct-bench between the water-proofing and the concrete. These were cared for much in the same manner as the springs in the rock, by pipes set in grooves cut in the duct-bench and leading the water to the drains. After the tunnels were completed, these pipes were plugged temporarily, and, if the water did not then find an outlet into the tunnel at some other point, they were grouted, but in a few instances it was found necessary to allow them to run.

There were many small springs in the excavation for the *B-D* portal, and, on account of the great number, the low points in the rock were filled with concrete before the forms were set, in order to crowd out as many of the springs as possible and combine others. The remaining flow was then conducted through grooves, cut in the concrete and rock and covered with sheet iron, to a sump near the northeast corner of the excavation. The result was very good, as far as caring for the water during concreting was concerned, but, after the concrete was placed to the duct-bench level and the back-filling was completed to a point about 2 ft. below that level, a large stream of water found its way between the concrete and the water-proofing and rose to the floor level, 2 ft. above the back-filling, where it poured out over the top of the water-proofing then in place. No attempt had been made to seal the bottom of the water-proofing, as was subsequently done, and it was found necessary to dig down and remove about 6 in. of it and form a seal with brick.

FIG. 1.—PORTAL OF TUNNELS *B-D*.

FIG. 2.—PORTAL OF TUNNELS *B-D* BEFORE CONSTRUCTING ARCH.

Construction for Overhead Tracks.

At the time the small piers for Line 13 were constructed, it was anticipated that some movement would occur in them when the filling for the surface tracks was made about their bases, and, to prevent individual piles from moving at different rates and being broken or torn loose from the pier they supported, the sheeting was left in place. The tendency to move was not over-estimated, as a difference in elevation of 2 ft. on opposite sides of a pier, even if none of the fill touched it, caused movement away from the fill, which, however, was readily counterbalanced by placing a slight excess of fill on the opposite side. The maximum movement noted in any of these piers was $1\frac{5}{8}$ in., and the maximum variation from the original position at the completion of the fill was $\frac{5}{8}$ in.

The original plans for the approach to the double-track viaduct for the overhead freight line contemplated an earth embankment supported by two gravity retaining walls resting for most of their length on piles. The action of the small piers noted above made it plain that it would be, not only expensive, but difficult, where the embankment was high, to construct the walls so as to keep them in their original position. The grade and location of the adjoining tracks were such as to permit the earth embankment to take its slope on the south side for a length of 368 ft. of the easterly end of the approach, while requiring that the north slope be retained. The maximum difference in elevation of the tracks on the approach and north of it being for this length only 10 ft., the gravity wall was used.

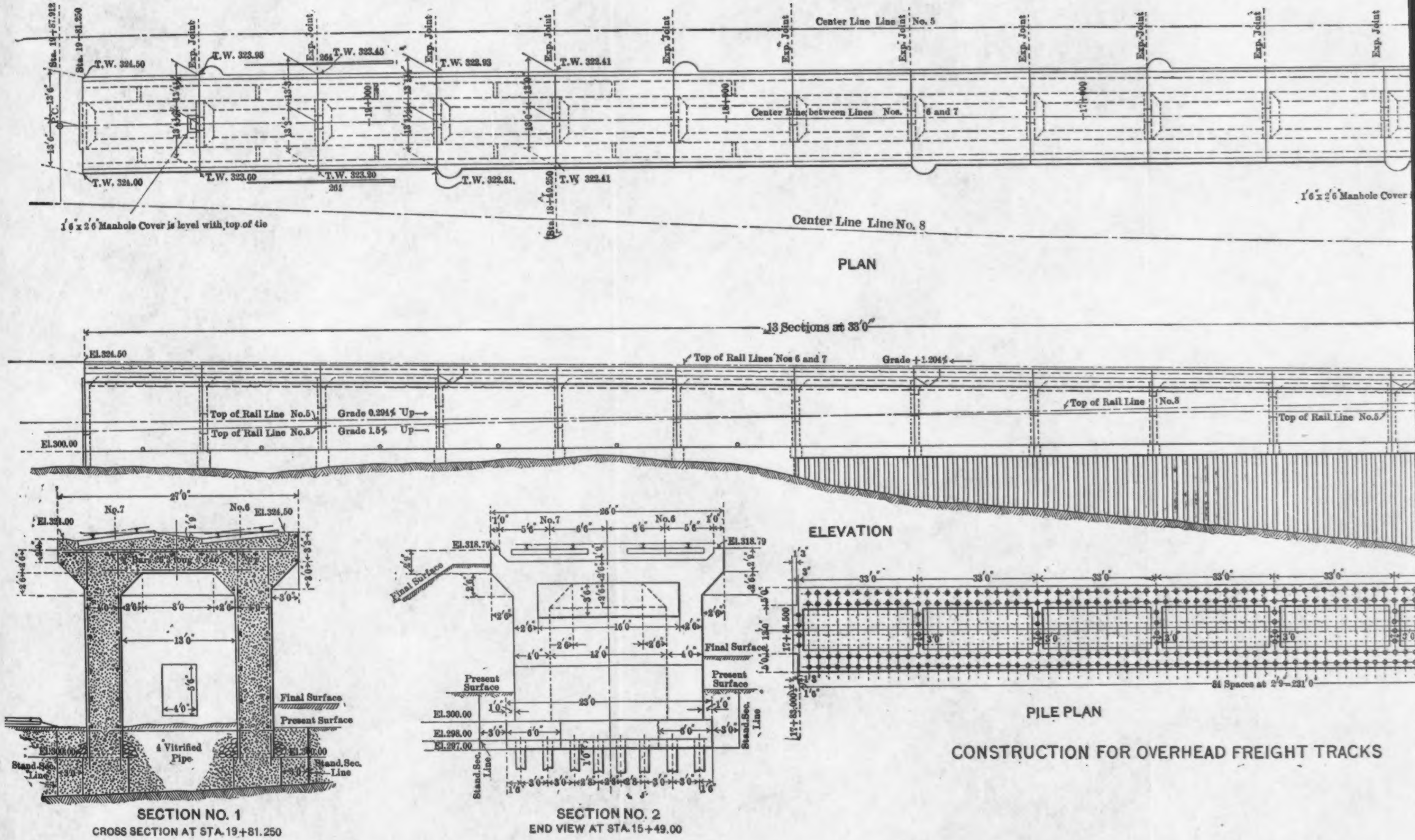
A length of 142 ft. of the easterly end of the gravity wall, which retained only from 5 to 7 ft. of embankment, was founded on the old roadbed of the Long Island Railroad, while the remaining 226 ft. was founded on pile bents, spaced 4 ft. from center to center, and containing three and four piles in the alternate bents. Between each pair of vertical bents two batter piles were set at an angle of 20° from the vertical.

As stated above, the maximum difference in elevation of the two rails, which represents the height of material retained, was only 10 ft., and, in order to keep the piles below the ground-water level, the cut-off was 11 ft. below the low rail, which placed the major portion of the retaining wall below the surface, and seemed like unnecessarily expensive construction, but sufficient movement occurred in the low

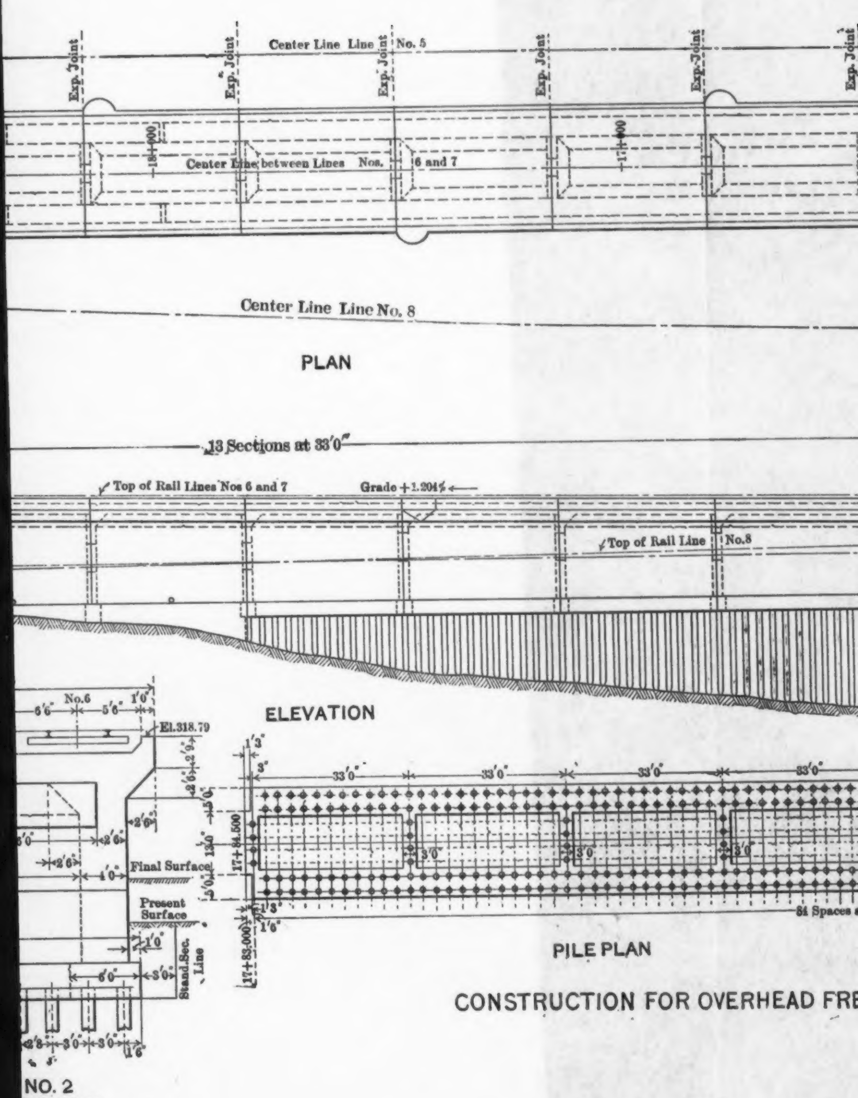
wall, founded on the old roadbed, to justify the additional expenditure on the higher wall.

From the westerly end of the gravity wall to the abutment, a distance of 528 ft., the cellular design shown on Plate XXXVII was adopted. This is an unusual design, but has the advantage of being not only more stable than two retaining walls on piles, but less expensive, while, as compared with small piers and steel girders, it will probably prove more economical in the end, and has the advantage of presenting a continuous surface to any cars which may be derailed from the shifting tracks immediately adjoining it on the north and south.

The work was built in sections 33 ft. long, that being the distance between the cross-walls or bulkheads, and each section was constructed in two lifts, the first being both side-walls and bulkhead from the top of the piles or rock to a line about 1 ft. below the finished grade of the adjoining tracks, and the second, side-walls and bulkhead above that point, and roof. The construction was carried on from the west toward the east, the height of the structure diminishing in that direction and thus permitting sections of the form to be removed as the work advanced. Each bulkhead, of course, was built in conjunction with the section east of it, the rear forms for the bulkheads being the only ones that had to be knocked apart and rebuilt as the work advanced, and the timber forming them was passed ahead through the 4 by $5\frac{1}{2}$-ft. openings shown on Section No. 1, Plate XXXVII. The interior movable form is shown by Fig. 8. It was slacked off by removing the key and tightening the turnbuckles, and, at the same time, removing wedges from under the base, the two sections, of 3 ft. 2 in. each at the bottom, being those removed as the height of the structure diminished. A view of this form and likewise the outside form is shown by Fig. 2, Plate XXXII. The outside form was built in two sections and picked up and swung ahead by the derricks which handled the excavation and concrete. The braces used for the outside form are shown by Fig. 1, Plate XXXVIII, and, in addition to those braces, the outside and inside forms were bolted together by three lines of $\frac{3}{4}$-in. bolts spaced at 4-ft. centers. Fig. 1, Plate XXXVIII, shows the northerly side of the abutment, which was built to conform to the cellular approach, and Fig. 2, Plate XXXVIII, shows the cellular work from the south side; the east end of the first pier for the steel superstructure is also shown in the foreground.

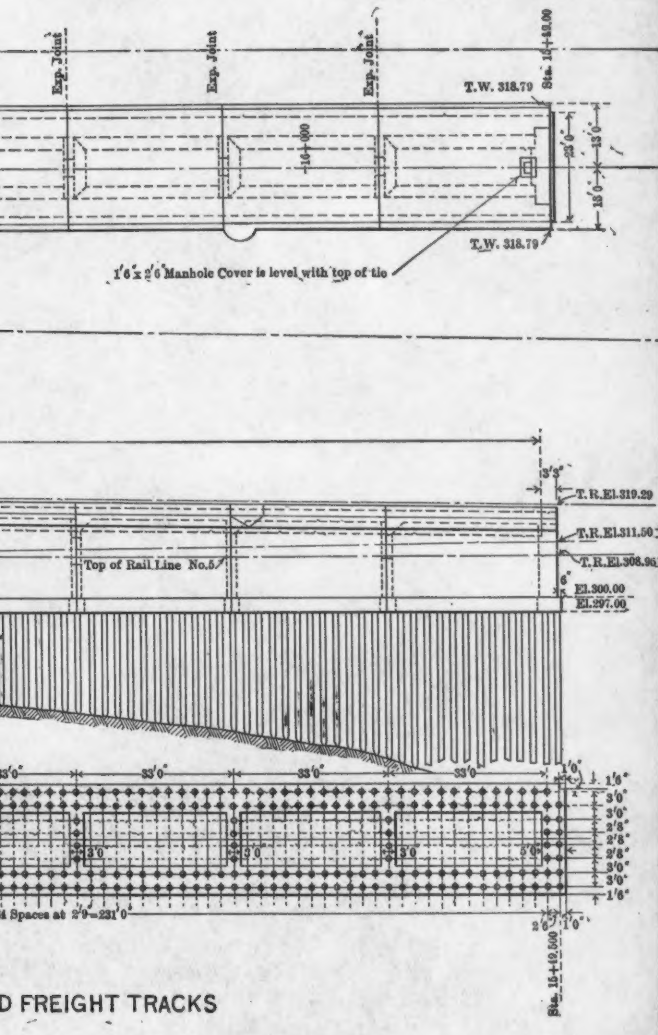


CONSTRUCTION FOR OVERHEAD FREIGHT TRACKS

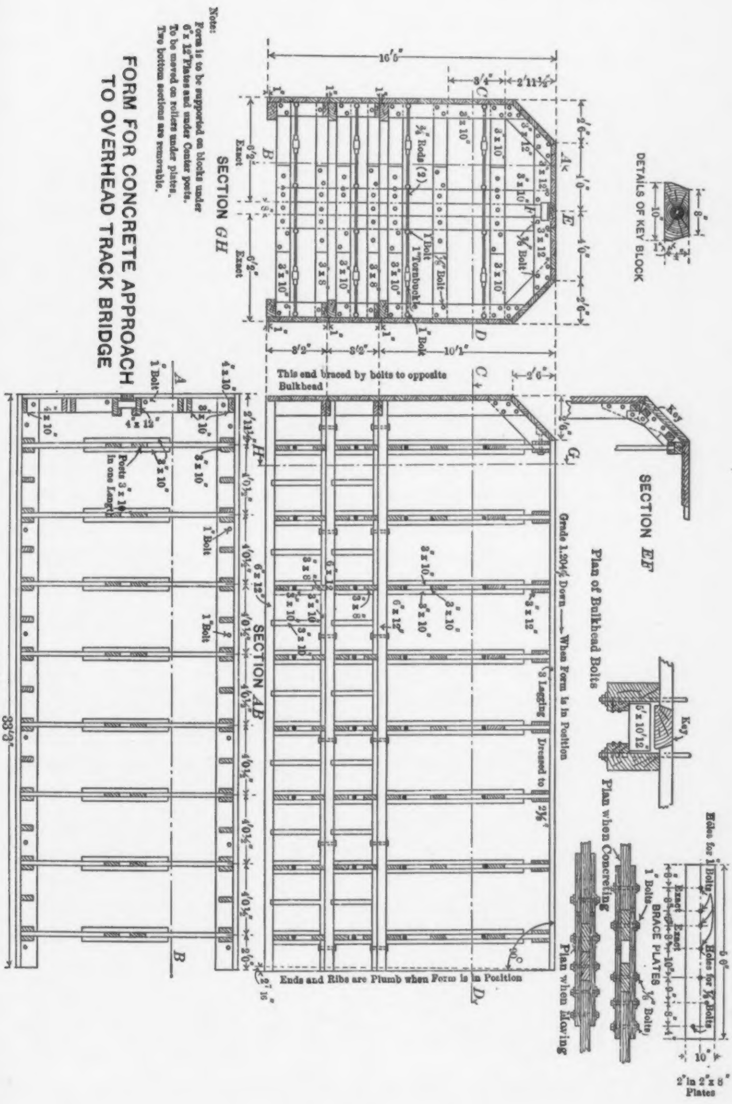


CONSTRUCTION FOR OVERHEAD FRE

PLATE XXXVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1162.
CLARKE ON
PENN. R. R. TUNNELS:
APPROACHES TO EAST RIVER TUNNELS.



D FREIGHT TRACKS



FORM FOR CONCRETE APPROACH TO OVERHEAD TRACK BRIDGE

FIG. 8.

Plant and Operation.

The contractors' plant can be classified under seven headings:

Dock Plant,
Stone-Crushing Plant,
Transportation Plant,
Mud-Disposal Plant,
Pile-Driving Plant,
Concrete-Mixing Plant,
Excavating and Constructing Plant.

The power used was steam furnished by seventeen boilers located at different points on the work, as will be hereafter described, the units varying from 20 to 125 h.p.

Dock Plant.—The dock plant was located at the foot of Hunter's Point Avenue, on Dutch Kills Creek, on a dock built by the contractors on ground leased from the Long Island Railroad and private parties, the contractors having, under a permit from the City, laid tracks on Hunter's Point Avenue, then closed to traffic, from the dock to the site of the construction, a distance of 1 700 ft. Parts of the dock are shown by Figs. 1 and 2, Plate XXXIX. This plant consisted of three stiff-leg derricks, two operated by Lidgerwood, 7 by 10-in. and 8¼ by 10-in., double-drum engines with 20-h.p. boilers mounted on the same frame, and Mead-Morrison, 4½ by 6-in., swinging engines, used for handling cement, brick, piles, timber, and other heavy materials delivered to the work by boat. The third, shown by Fig. 1, Plate XXXIX, was operated by similar Mundy, 8 by 12-in. engines, but by steam from a separate 80-h.p. boiler, which also furnished power for a carpenter and machine shop. This derrick handled sand and stone from scows directly to cars, and, during intervals, when no cars were present, to the bins, from which the supply was drawn when no scows were on hand.

The cement was likewise usually delivered from canal-boats directly to cars, but an emergency supply was at all times kept in a warehouse at the dock having a capacity of 750 bbl.

The carpenter and machine shop, shown just back of the cement shed in Fig. 2, Plate XXXIX, contained two 36-in. circular saws (one rip and one cut-off), one drill-press, one bolt machine, one pipe-cutting and threading machine, and the usual hand tools.

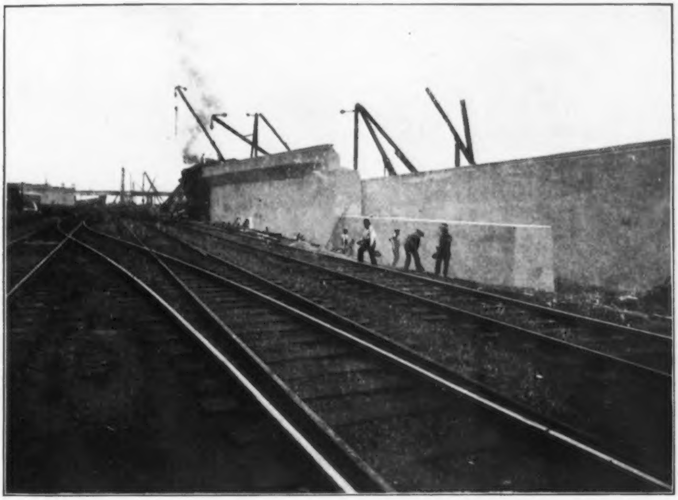


FIG. 1.—ABUTMENT FOR OVERHEAD FREIGHT TRACKS.

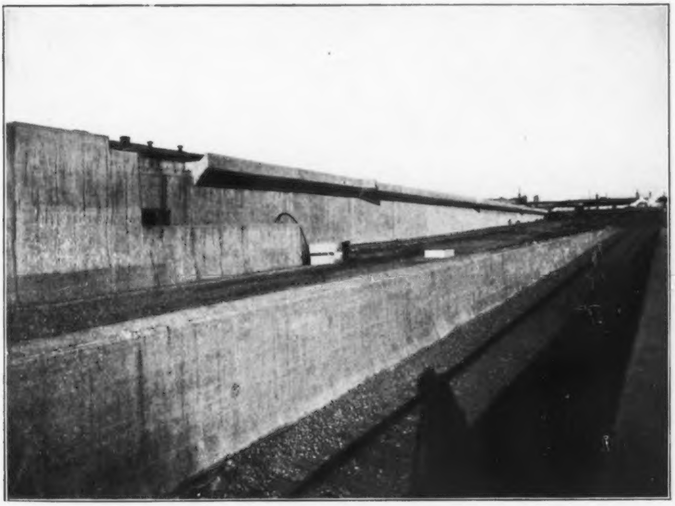


FIG. 2.—CONCRETE APPROACH TO OVERHEAD TRACK BRIDGE.

The circular saws were used largely for making ties and rough form timber from pile butts and rejects, but also to some extent in framing the heavier forms.

Stone-Crushing Plant.—The stone-crushing plant was near East Avenue on the southerly side of the rock excavation for the tunnels, in which position much of the rock could be handled to it directly by the excavating derricks and the remainder by a very short haul in dump-cars. The plant consisted of two (No. 5 and No. 7½) McCully crushers, erected so that the tops of the charging hoppers were only 4 ft. above the general surface of the ground, and a belt and bucket conveyor for carrying the crushed stone to screens set above bins for stone and dust which were elevated sufficiently to empty into cars by gravity. The power was furnished by a battery of three boilers, two of 125 h.p. each and the third of 100 h.p., which battery furnished steam also for drilling and for operating part of the derricks used in excavating rock and placing concrete on the adjacent work.

Transportation Plant.—The transportation plant consisted of four 10 by 16-in. American, two 10 by 16-in. Davenport, and two 9 by 14-in. Davenport locomotives, fifty-eight 4-yd. and six 3-yd. "Western" dump-cars, and sixteen 5-ton flat cars, all of 3-ft. gauge.

Mud-Disposal Plant.—The mud-disposal plant was made necessary by the impossibility of maintaining tracks on the swamp land south of Meadow Street, where the excavated material unsuitable for embankment was wasted. It consisted of two scrapers, specially rigged so as to be operated and dumped by double-drum, hoisting engines mounted on travelers which moved backward and forward on the edge of the swamp. The rigging of the scraper is shown by Fig. 9, the scraper being pulled forward by the rope, *a,* which passed through a sheave attached to a deadman on the opposite side of the swamp from the traveler, while the rope, *b,* was allowed to run loose, as shown in the upper part of Fig. 9, until it was desired to dump the scraper, which was accomplished by clamping the lower drum, operating the rope, *a,* and pulling on the rope, *b,* until the scraper was in the position shown in the lower part of Fig. 9, when a slight pull on the rope, *a,* with the rope, *b,* slacked a corresponding amount, completed the turn. The scraper was then pulled back to the starting point by the rope, *b.*

Pile-Driving Plant.—Most of the pile-driving was done by three No. 2 Warrington steam hammers, with 3-ft. stroke and moving parts weighing 3 000 lb., mounted in 45- to 48-ft. leads of the usual type, and raised and lowered by 8¼ by 10-in., double-drum, hoisting engines mounted on the platforms of the drivers. These engines also moved the piles from the side of the excavation, at which point they were delivered by train, to the leads, and moved the drivers about by lines passed through snatch blocks and to the nigger-heads. Some piles which could not well be reached by the steam machines were driven by 2 000-lb. drop-hammers in 22- to 25-ft. swinging leads, supported by the derricks and raised by the derrick engines.

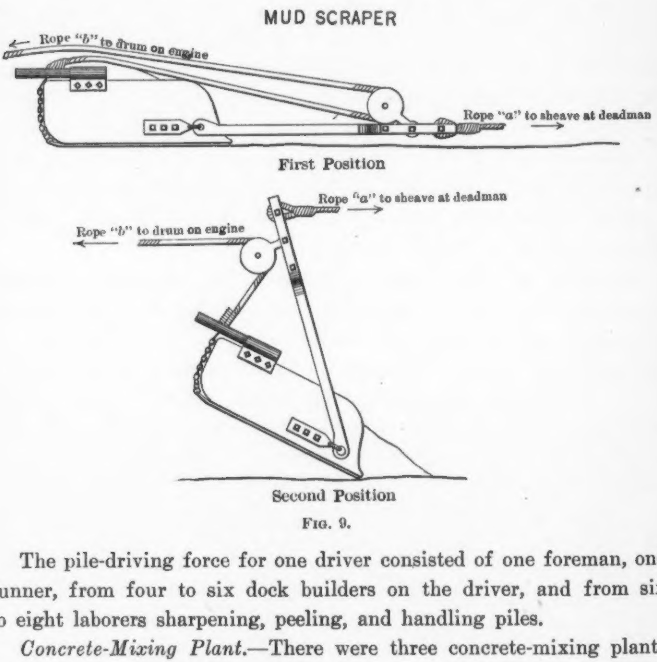


FIG. 9.

The pile-driving force for one driver consisted of one foreman, one runner, from four to six dock builders on the driver, and from six to eight laborers sharpening, peeling, and handling piles.

Concrete-Mixing Plant.—There were three concrete-mixing plants in use on the work at different times, but, as they varied only in the method of charging, a description of the last erected will answer. It was located just south of Tunnels *B* and *D*, near their portals, and is shown by Fig. 1, Plate XL, with the charging car in the act of dumping.

FIG. 1.—VIEW OF DOCK PLANT.

FIG. 2.—VIEW OF DOCK PLANT.

Fig. 2, Plate XL, shows the sand- and stone-bins, and the cement-house over the charging track, with the supply tracks supported on the timber structure forming the bins, the one in the foreground leading from the crusher and the one curving to the right and crossing the temporary tracks of the Long Island Railroad overhead, to the dock previously described. The framing of the bins and the arrangements for loading the charging cars are shown on Plate XLI. The arrangement of the mixer and the charging cars are shown on Fig. 10.

It will be noted that the charging car had two doors, both of which were closed by gravity when the car was in a horizontal position, the front door being held shut by a latch on either side of the car. The second door, which divided the car into two compartments, the forward one for sand and the rear one for stone, was prevented from swinging back of its normal position by two bolts running through the bottom of the car. In charging, the sand compartment was first filled, thus preventing the intermediate door from swinging forward when the stone charge was received. The two compartments of the car were graduated, and the upper limits of the charge of sand and stone were marked by angle irons riveted to the sides; the quantity of cement was determined by counting the bags. The rear axle carried two sets of wheels, the first being the running wheels, of the same gauge and tread as the forward pair, and the second, having a small tread and a 5-ft. gauge, dumped the car by engaging a pair of rails at the head of the incline which continued to elevate the rear of the car while the front traveled on the level. The latch being tripped automatically when the rear of the car was raised, both doors opened by gravity and discharged into the hopper of the mixer. The water was measured in a cylindrical iron tank on the upper platform of the mixer, the quantity being regulated to suit the conditions of the sand and stone. Inlet and outlet valves, operated by the mixer runner, controlled the quantity, which was determined by an indicator attached to a float in the tank. The concrete was mixed in a 5-ft. cubical mixer, made by Thomas Carlin and Sons Company. It was belt-driven by a 10 by 10-in. Metropolitan, horizontal engine located on the ground under the incline, and discharged directly into 2-yd. Stuebner buckets standing on flat cars. The mixture was of 1, $2\frac{1}{2}$, and 5 parts, by volume, and each charge contained 10 bags of cement; when deposited in the work this made 1.84 cu. yd. of concrete.

The force required to charge and operate the mixer was as follows: one foreman, one runner, one signalman, two sand and stone chargers, and four top men who handled cement and dumped cars, etc., etc. The largest amount of concrete turned out during any single shift, which in this case was of 11 hours duration, was 257 batches, equal to 473 cu. yd. measured in place.

Excavating and Constructing Plant.—The excavating plant, all of which, with the exception of the steam shovels and drills, was likewise used in building and moving forms and in placing concrete, consisted of one Thew, automatic, steam shovel, one Bucyrus, 70-ton shovel, but little used, one guy derrick with 80-ft. boom and 82-ft. mast, and twelve stiff-leg derricks having masts varying from 38 to 47 ft. and booms from 65 to 80 ft. Nine of the derricks, used in excavating swamp mud and other soft materials, were operated by 9 by 10-in. Mead-Morrison, or 8 by 12-in. Mundy, three-drum engines, and equipped with 1-yd., orange-peel buckets, the others were driven by 8¼ by 10-in., double-drum, Lidgerwood engines, with the usual 1-yd. and 2-yd. dump-buckets. All derricks had in addition 4½ by 6-in. Mead-Morrison, boom-swinging engines.

There were two travelers, each carrying two of the derricks noted above, together with their engines, and one 50-h.p., return-tubular boiler (shown in Fig. 1, Plate XXXII). The derricks were the shortest of those described, having 38-ft. masts and 65-ft. booms, and the engines were of the three-drum type required to operate the orange-peel buckets.

The travelers were 40 ft. from gauge to gauge, and were supported on 14 wheels, 7 to a side, of which 2 were directly under the foot-blocks of the derrick. When working, they were supported free of the rails by blocking between the outer sills of the travelers and the track ties.

Superstructure for Hunter's Point Avenue Viaduct.

Hunter's Point Avenue Viaduct is a steel-girder-and-column structure with a reinforced concrete floor having a 42-ft. roadway and two 10-ft. sidewalks. It is 328.5 ft. long, from face to face of back-walls, and the ends are skewed at an angle of 37°, the steel bents being on approximately the same angle. The steelwork was furnished by the Pennsylvania Steel Company, and the concrete floor was built by the Snare and Triest Company, which, as sub-contractor for the Pennsylvania Steel Company, also erected the steel.

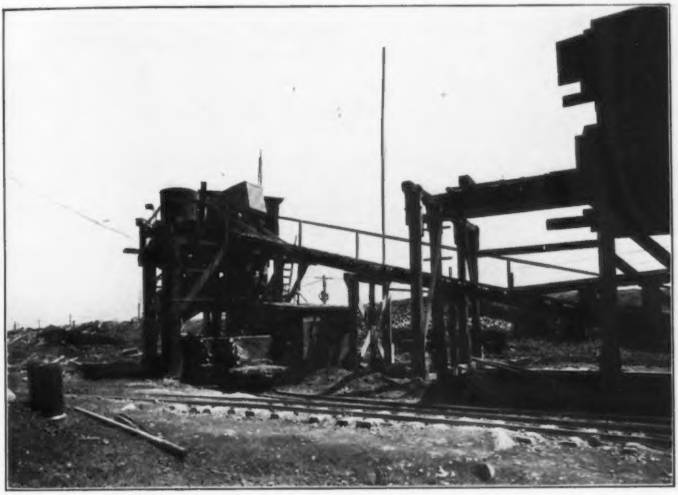


FIG. 1.—VIEW OF CONCRETE MIXING PLANT.

FIG. 2.—VIEW OF CONCRETE MATERIAL BINS AND TRACKS.

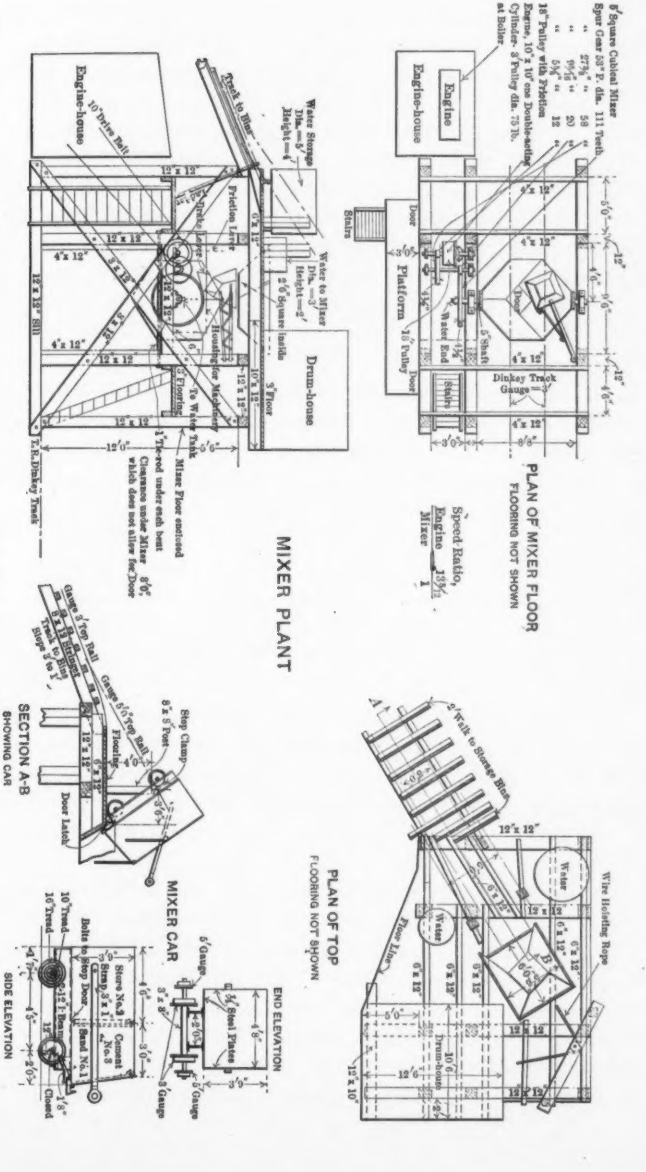

MIXER PLANT
PLAN OF MIXER FLOOR
FLOORING NOT SHOWN
PLAN OF TOP
FLOORING NOT SHOWN
SECTION A-B
SHOWING CAR
MIXER CAR
END ELEVATION
SIDE ELEVATION
Engine-house
Engine
Drum-house
Platform
Stairs
Dinkey Track
Gauge=3'
Water Storage
Wire Hoisting Rope
Floor Line
Track to Bins
Speed-Ratio,
Engine / Mixer = 13 3/4 / 1

FIG. 10.

The design and construction are so similar to that of the longer viaduct at Thomson Avenue, described in some detail in the paper by Mr. L. H. Barker, that only one feature, a rather unusual one in plate-girder construction, will be mentioned. In the northerly span, No. 1, only 3 ft. was available for depth of girder, and in Span No. 3 only 4 ft. 2 in., while Span No. 2, being over the approach to Tunnel *C*, permitted a much deeper girder. Advantage was taken of this condition by cantilevering the girders of Span No. 2 20 ft. beyond the center line of the first column bent and 15½ ft. beyond the second column bent, thus reducing the spans of the first and third girders to 43 ft. and 58 ft. 9 in., respectively, as shown in Fig. 1, Plate XLII.

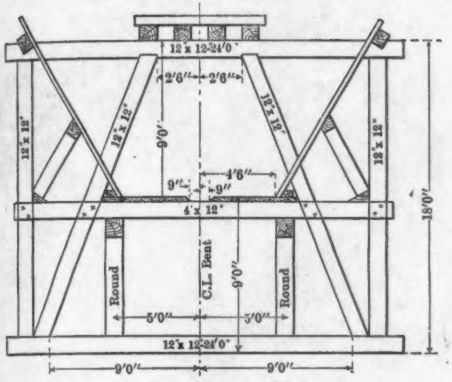
Superstructure of Overhead Freight Bridges.

The steel superstructure of the overhead bridges for Tracks 6, 7, and 13 was designed to carry the live loads defined in the Standard Specifications for Steel Railroad Bridges issued by the Pennsylvania Railroad Company. This consists of two consolidation engines followed by a uniformly-distributed train load of 5 000 lb. per lin. ft. of track.

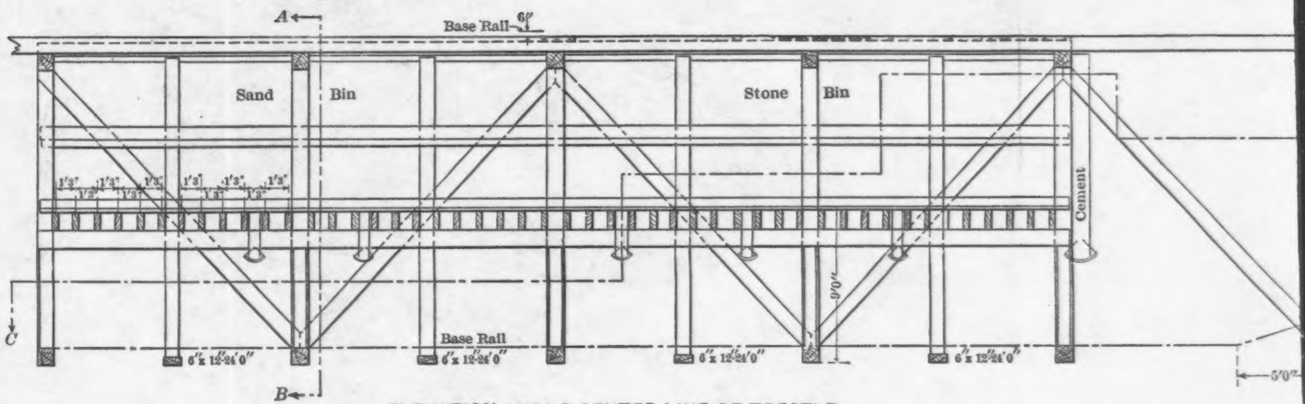
The double-track deck structure carrying Lines 6 and 7 is on a 9° curve. The tracks are 14 ft. from center to center, and the reinforced concrete floor, being 32 ft. wide, serves, not only as a support for the ballast and tracks, but also as a protection to trains passing underneath.

The area under the bridge is practically covered by the invert approaches to the tunnels and by surface tracks parallel to them, which necessitated constructing all supports for the bridge likewise parallel and therefore on varying and, toward the northerly end of the bridge, on very acute angles with the center line. Bracing was prevented, as the head-room was limited.

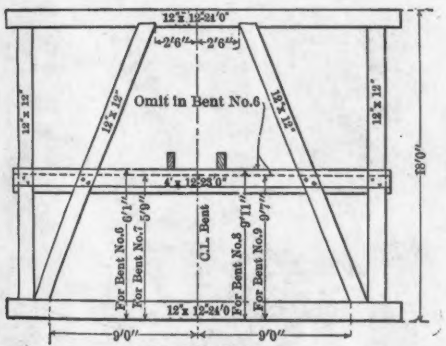
The bridge is composed of thirteen spans, and is divided into nine practically independent structures by expansion joints. The making of each structure stable on lines perpendicular to the supporting piers required rather unusual treatment. The first three sections are composed of simple beams resting at one end on the abutment and at the other supported by a pier of full height, which, on account of the acute angle mentioned above, was 234 ft. in length. This pier also carried one end of and gave lateral support to sections four and five. The



SECTION *A B*

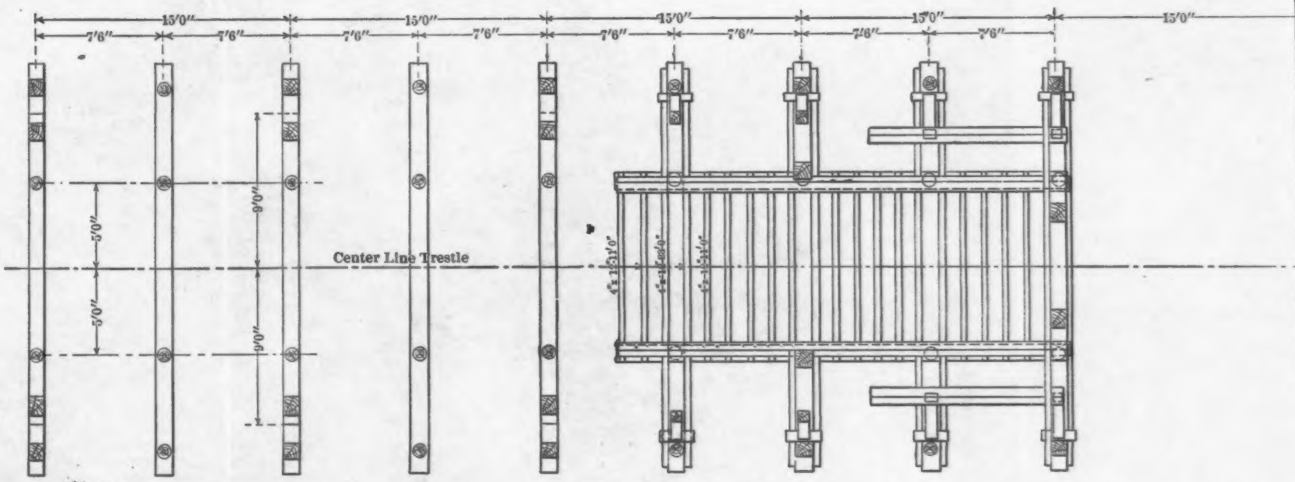


ELEVATION ALONG CENTER LINE OF TRESTLE

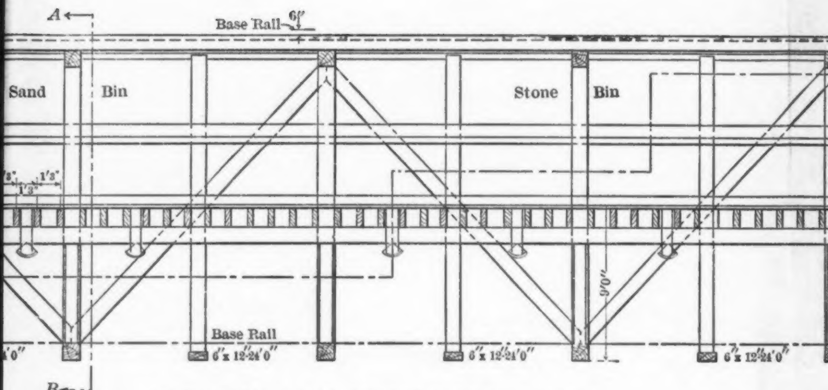


SECTION *E F*
BENTS-Nos.6, 7 AND 8

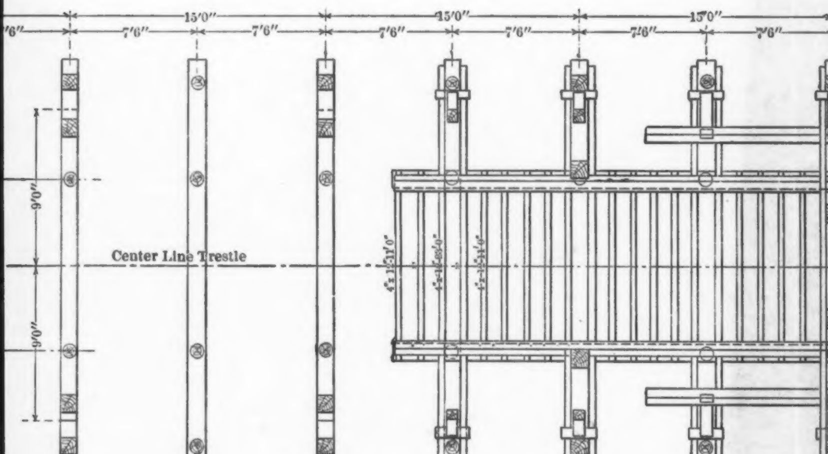
PLAN FOR
STORAGE BINS FOR CONCRETE MIXING PLANT.



SECTION *G D*



ELEVATION ALONG CENTER LINE OF TRESTLE



SECTION *CD*

PLATE XLI.
TRANS. AM. SOC. CIV. ENGRS.
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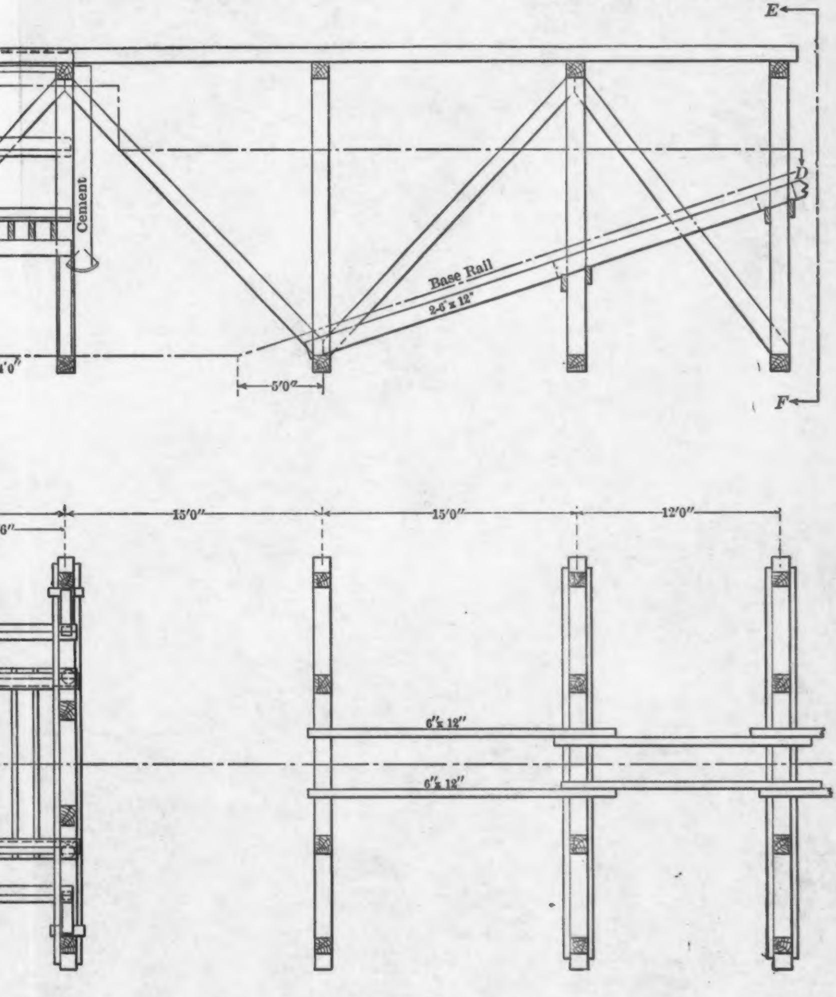
CLARKE ON
PENN. R. R. TUNNELS:
APPROACHES TO EAST RIVER TUNNELS.



southerly end of the bridge is likewise supported on and anchored to a pier of full height, which gives ample stiffness to the ninth section. The intermediate four sections are supported on steel columns, but stiffness is obtained by double bents, 6 and 8 ft. apart, respectively, at two points, where the spacing of the tracks permits, which, being securely interbraced, form towers, as shown by Fig. 2, Plate XLII.

In Spans Nos. 1 and 2 the steelwork is entirely embedded in concrete, as they cover tracks which will be operated by steam locomotives, while the remainder of the steel, being over electrically-operated tracks, is unprotected, the concrete floor being merely a slab.

In proportioning the material for the reinforced concrete floor, the extreme stress on concrete in compression was calculated not to exceed 500 lb. per sq. in., the shearing stress in concrete, 50 lb. per sq. in., and the tensile stress in the steel, 16 000 lb. per sq. in.

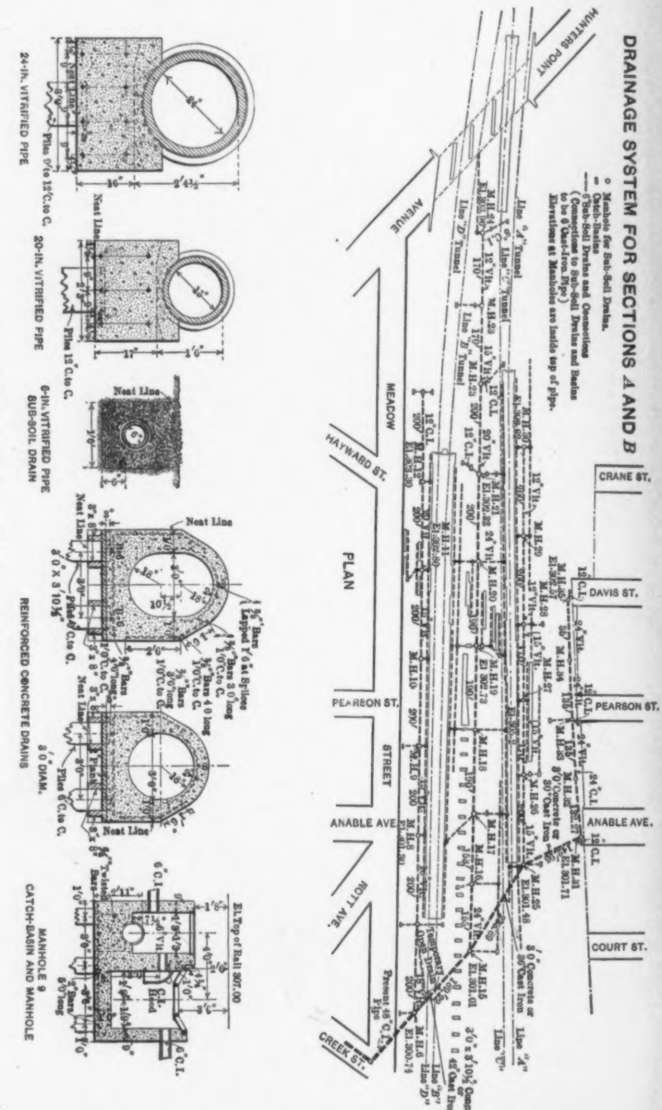
The steelwork was furnished and erected by the McClintic-Marshall Construction Company, and the concrete floor and protection by the Wilson and English Construction Company.

Drainage System.

The finished surface between Hunter's Point and Thomson Avenues is much in the form of a dish, the grade dropping from both avenues toward the center, and both Meadow Street and the ground north of the yard being above the level of the tracks, the lowest of which, in the vicinity of Davis and Pierson Streets, are but 5.2 ft. above mean high tide, with the sub-grade 2 ft. lower.

The city sewers in the vicinity are small and few, and too high to care for any of this area, making a private system necessary. The most available outlet was the turning basin built at the head of Dutch Kills Creek by the Degnon Realty and Terminal Improvement Company, and, as the only approach to that basin was over the property of the Realty Company, arrangements were made with them to construct a 4-ft. cast-iron outlet sewer from the Railroad Companies' property on the northerly side of Meadow Street to the basin. The remainder of the system was constructed, under a separate contract, by Naughton Company and Arthur McMullen. The layout is shown by Fig. 11.

The top of the intrados at the outlet was located at Elevation 300, mean high tide, and on the hydraulic gradient for that stage of the



DRAINAGE SYSTEM FOR SECTIONS *A* AND *B*

STANDARD CROSS-SECTIONS OF DRAINS

Fig. 11.

PLATE XLII.
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APPROACHES TO EAST RIVER TUNNELS.

FIG. 1.—HUNTER'S POINT AVENUE BRIDGE: CANTILEVER GIRDER.

FIG 2.—VIEW OF OVERHEAD, DOUBLE-TRACK FREIGHT BRIDGE.

tide throughout. The sizes were fixed for a full pipe at that stage, with a run-off of 2 in. per hour from the concrete inverts and 1 in. per hour from the remainder of the area drained. It was recognized that the latter run-off is large for a railroad yard, but as the grades were flat and the ditch room limited, it was necessary to place catch-basins at frequent intervals over most of the area. It was impossible to locate surface ditches over a considerable portion of the area, and, therefore, sub-soil drains were laid, as shown by Fig. 11, the lower half of each joint in the pipe being left open, the upper half cemented, and the stone covering carried to the surface, it being intended that the drains should act as conduits for surface-water rather than perform the usual functions of sub-soil drains. Both the sub-soil drains and ditches empty into catch-basins having their bottoms well below the outlet to the sewer, as shown in Manhole 9, Fig. 11.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1163

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE SUNNYSIDE YARD.*

By Louis H. Barker, Esq.†

One of the sections of the East River Division of the New York Tunnel Extension of the Pennsylvania Railroad is called The Sunnyside Yard. It is the terminal passenger yard of that railroad in New York City, and is located in Long Island City, Borough of Queens, about 3.5 miles from the Terminal Station and 1.6 miles eastward from the East River. The name Sunnyside is derived from the local name of the neighborhood. The Sunnyside Yard Section extends from 10 ft. west of Thomson Avenue to the west side of Woodside Avenue, a distance of 8 500 ft., has a maximum width of 1 625 ft., and embraces 208 acres.

This paper gives a description of the general plan of the Yard, together with some of the special features of its design and construction.

General Plan.

The general plan of The Sunnyside Yard, Plate XLIII, was prepared by a committee appointed for that purpose. On June 15th, 1906, it was submitted to the Board of Estimate and Apportionment of the City of New York, with an application for the required change

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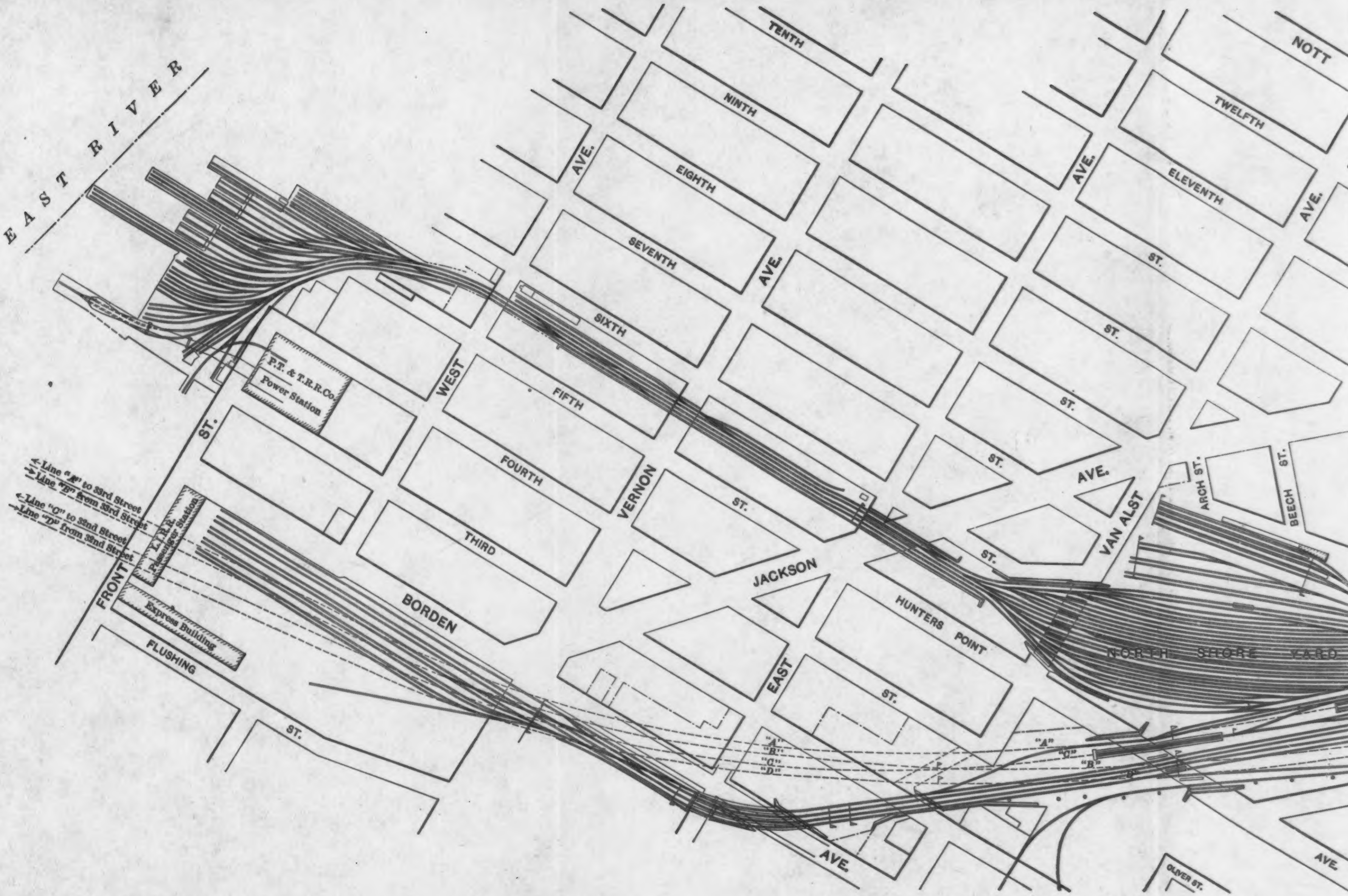
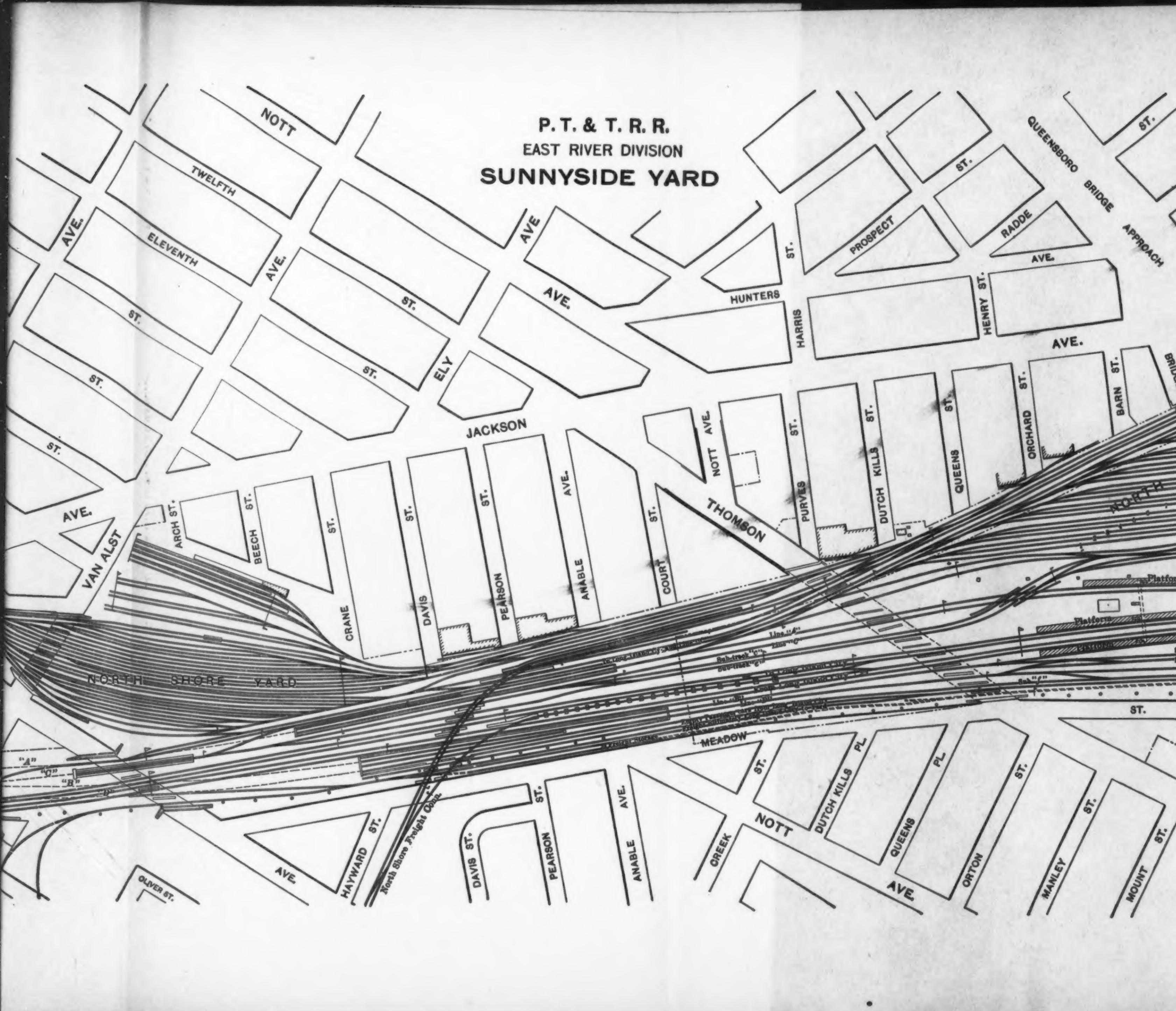
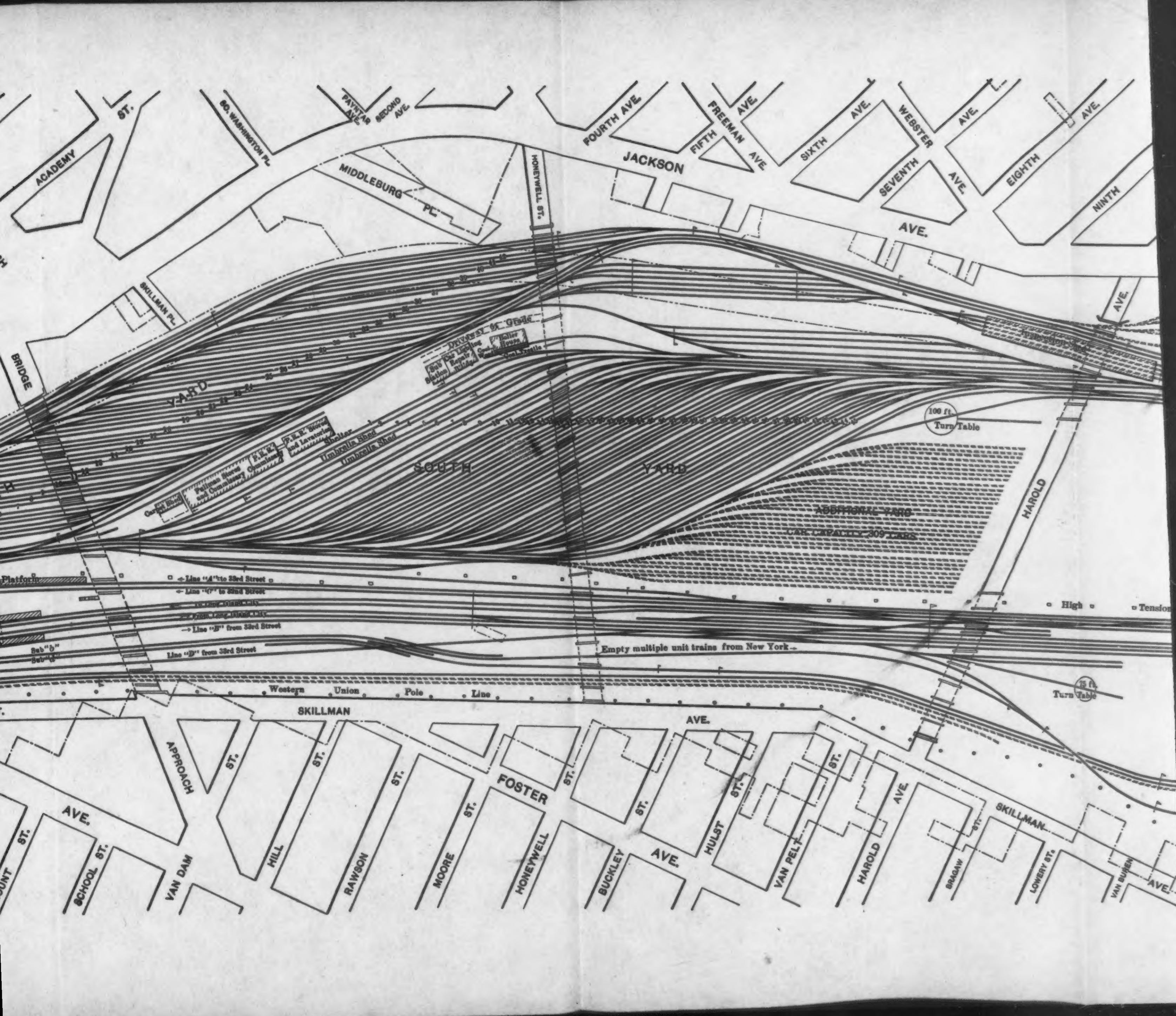
* Presented at the meeting of September 21st, 1910.

† Res. Engr., The Sunnyside Yard, Pennsylvania Tunnel and Terminal R. R. Co.


EAST RIVER
P.T. & T.R.R.Co.
Power Station
Line "A" to 33rd Street
Line "B" from 33rd Street
Line "C" to 32nd Street
Line "D" from 32nd Street
L.I.R.R.
Passenger Station
Express Building
FRONT ST.
WEST AVE.
VERNON AVE.
JACKSON AVE.
VAN ALST AVE.
EAST AVE.
FLUSHING ST.
BORDEN AVE.
THIRD ST.
FOURTH ST.
FIFTH ST.
SIXTH ST.
SEVENTH ST.
EIGHTH ST.
NINTH ST.
TENTH ST.
ELEVENTH ST.
TWELFTH ST.
NOTT AVE.
HUNTERS POINT AVE.
ARCH ST.
BEECH ST.
OLIVER ST.
NORTH SHORE YARD
"A"
"B"
"C"
"D"


P. T. & T. R. R.
EAST RIVER DIVISION
SUNNYSIDE YARD
NOTT
TWELFTH
ELEVENTH
AVE.
ST.
ELY
HUNTERS
HARRIS
HENRY ST.
PROSPECT
RADDE
QUEENSBORO BRIDGE APPROACH
JACKSON
NOTT AVE.
THOMSON
PURVES
DUTCH KILLS
QUEENS
ORCHARD
BARN ST.
BRIDGE
VAN ALST
ARCH ST.
BEECH
CRANE
DAVIS
PEARSON
ANABLE
COURT
NORTH SHORE YARD
NORTH
Platform
MEADOW
HAYWARD
DAVIS ST.
OLIVER ST.
CREEK
NOTT
DUTCH KILLS PL
QUEENS PL
ORTON ST.
MANLEY ST.
MOUNT ST.
North Shore Freight Conn.



ACADEMY
ST.
SO. WASHINGTON PL.
SECOND AVE.
MIDDLEBURG PL.
HONEYWELL ST.
FOURTH AVE.
JACKSON AVE.
FREEMAN AVE.
FIFTH AVE.
SIXTH AVE.
WEBSTER AVE.
SEVENTH AVE.
EIGHTH AVE.
NINTH AVE.
SKILLMAN PL.
BRIDGE
YARD
SOUTH YARD
Umbrella Shed
ADDITIONAL YARD
CAR CAPACITY 309 CARS
HAROLD
100 ft. Turn Table
Platform
Line "A" to 33rd Street
Line "C" to 33rd Street
Line "B" from 33rd Street
Line "D" from 33rd Street
Empty multiple unit trains from New York
High Tension
Western Union Pole Line
75 ft. Turn Table
SKILLMAN AVE.
APPROACH
ST.
HILL ST.
RAWSON ST.
MOORE ST.
FOSTER AVE.
HONEYWELL ST.
BUCKLEY ST.
HULST ST.
VAN PELT ST.
HAROLD AVE.
BRAGAW ST.
LOWERY ST.
VAN BUREN AVE.
SKILLMAN AVE.
SCHOOL ST.
VAN DAM ST.
AVE.

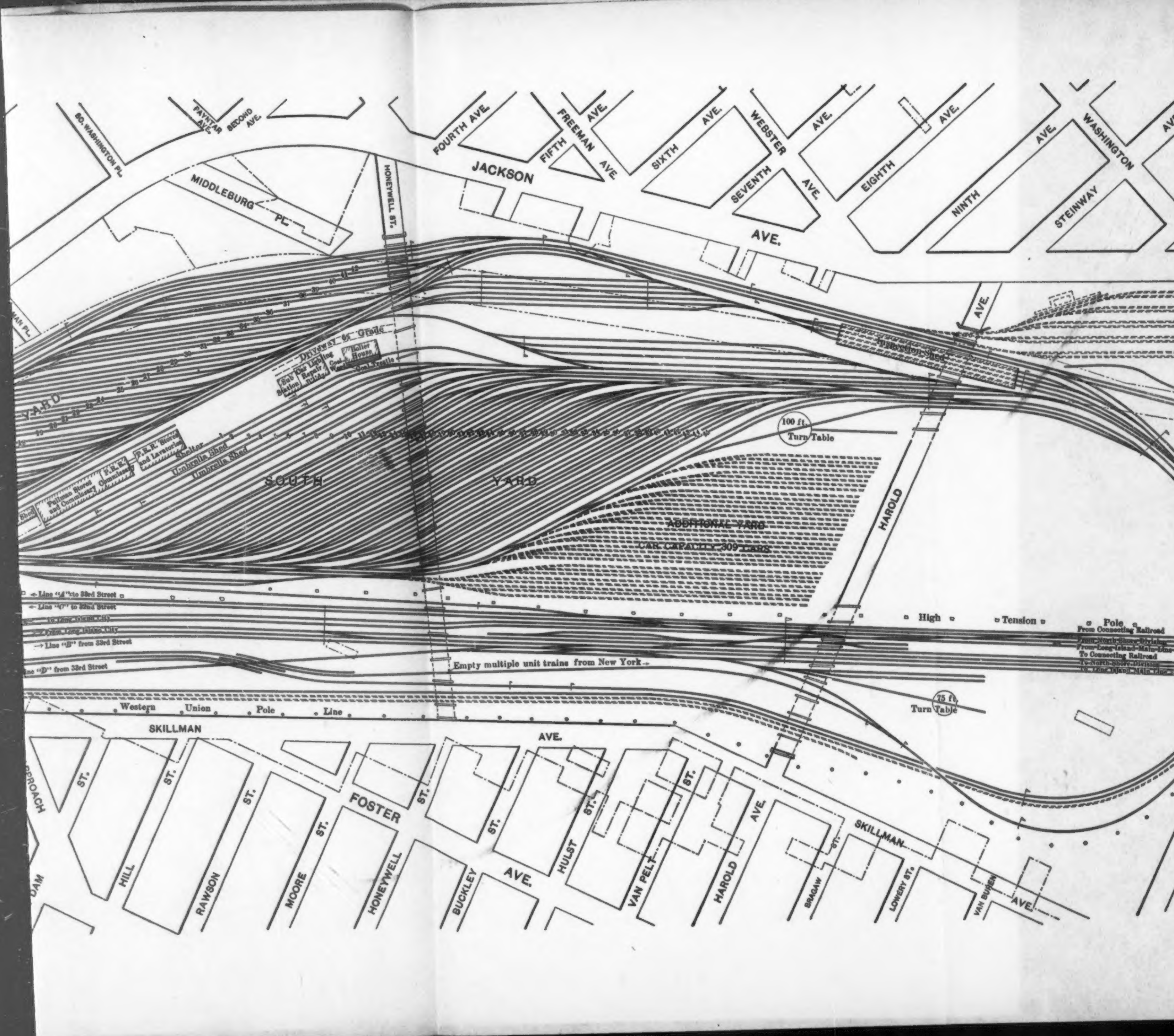
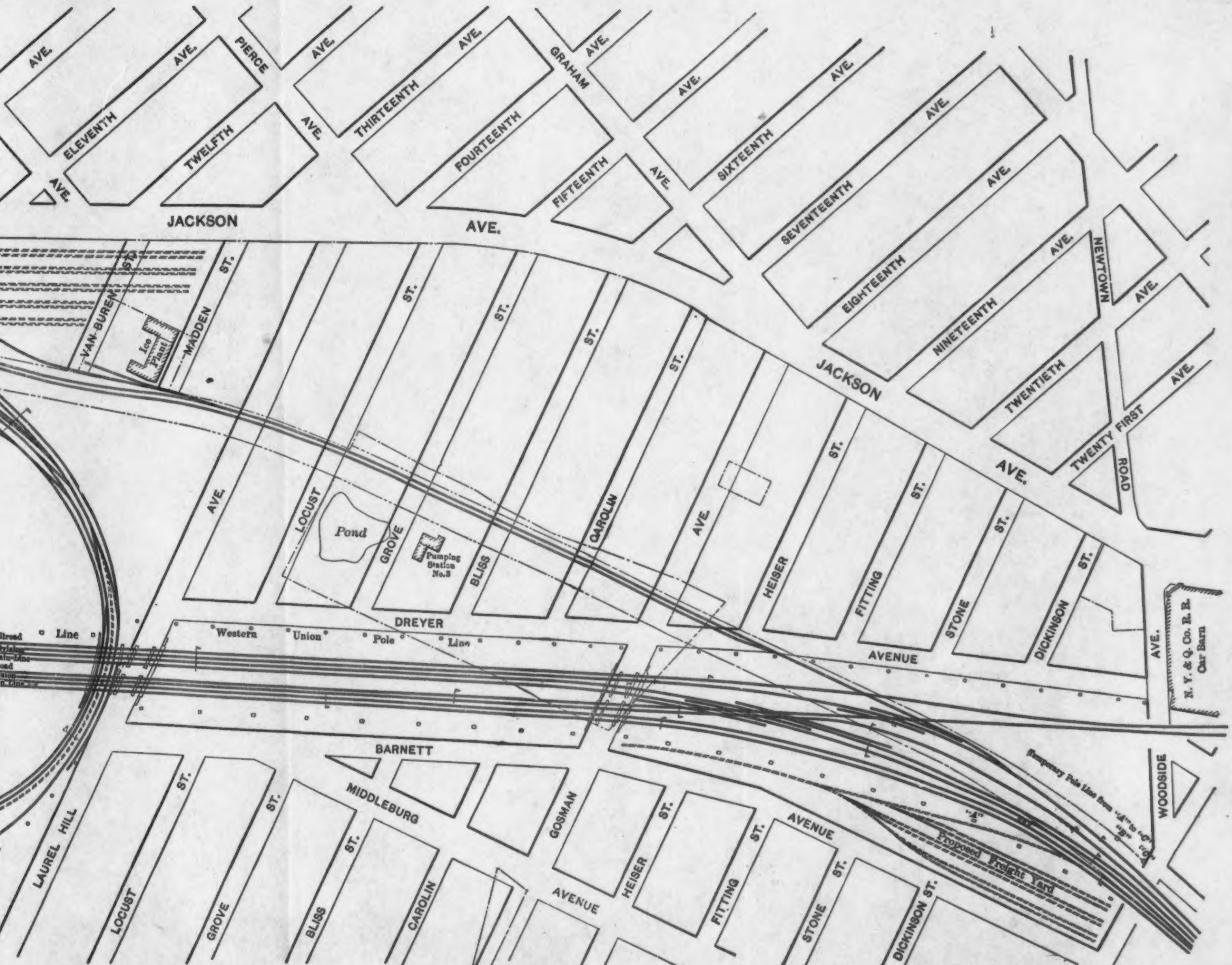

SO. WASHINGTON PL.
FAYNTAR AVE.
SECOND AVE.
FOURTH AVE.
FIFTH AVE.
FREEMAN AVE.
SIXTH AVE.
WEBSTER AVE.
SEVENTH AVE.
EIGHTH AVE.
NINTH AVE.
WASHINGTON AVE.
STEINWAY
JACKSON AVE.
MIDDLEBURG PL.
HONEYWELL ST.
YARD
Driveway 6% Grade
Sub Station
Car Lighting Repair
Coal Washing
Boiler House
Coal Trestle
Inspection Shed
Pullman Stores and Commissary
P.R.R. Commissary
P.R.R. Stores and Lavatory
Shelter
Umbrella Shed
Umbrella Shed
SOUTH
YARD
100 ft. Turn Table
ADDITIONAL YARD
CAR CAPACITY 309 CARS
HAROLD
AVE.
Line "A" to 33rd Street
Line "C" to 33rd Street
To Long Island City
From Long Island City
Line "B" from 33rd Street
Line "D" from 33rd Street
Empty multiple unit trains from New York
High Tension Pole
From Connecting Railroad
From North Shore Division
From Long Island Main Line
To Connecting Railroad
To North Shore Division
To Long Island Main Line
75 ft. Turn Table
Western Union Pole Line
SKILLMAN AVE.
APPROACH
ADAM
HILL ST.
RAWSON ST.
MOORE ST.
FOSTER AVE.
HONEYWELL ST.
BUCKLEY ST.
HULST ST.
VAN PELT ST.
HAROLD AVE.
SKILLMAN AVE.
SNAGAW ST.
LOWERY ST.
VAN BUREN AVE.

PLATE XLIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1163.
BARKER ON
PENNSYLVANIA R. R. TUNNELS: THE SUNNYSIDE YARD.



in the map of the City and the necessary permission to proceed with the work of construction. By resolution of that Board, on February 15th, 1907, the proposed changes in the City map were authorized, and after the execution of an agreement, between the City of New York, and the Pennsylvania, New York, and Long Island Railroad (now called the Pennsylvania Tunnel and Terminal Railroad), and the Long Island Railroad, dated June 21st, 1907, the plan was approved by the Mayor.

This agreement, in part, called for the following: The vacation of all or parts of 52 streets, Plate XLIV; the opening of portions of 5 streets; the changing of the grades of 15 streets; the construction of 8 highway bridges, 6 overhead (Van Alst Avenue, Hunter's Point Avenue, Thomson Avenue, Bridge Approach, Honeywell Street, and Harold Avenue), 2 undergrade (Laurel Hill Avenue, and Gosman Avenue); and 7 railroad bridges.

Sunnyside Yard, which is exclusively for passenger equipment, is divided into two separate yards, called "North Yard" and "South Yard." In the "North Yard" will be stored cars of the multiple-unit type used in connection with the suburban traffic; the "South Yard" will be used for storage, cleaning, and repairing Pullman cars, dining cars, and coaches. Between these two yards are located the necessary store, supply, and other yard buildings, together with a sub-station and boiler-house. A driveway is provided from Honeywell Street and a stairway from the Bridge Approach Viaduct leading to these buildings.

An important feature of the plan of the Yard is a loop at its east or rear end around which all empty trains will pass before entering it. The turning movement of the entire train by passing around the loop will avoid the necessity, existing at the present terminal at Jersey City, of uncoupling "observation" or other special cars, and turning one car at a time on a turn-table, which, together with the movement required through the crowded yard, makes it a very slow and expensive operation.

It is arranged that the empty trains will enter at one end and leave from the other end of the Yard, thereby avoiding conflicting movements and delay incident to a yard having the entrance and exit at the same end. The shifting movements of the trains found necessary after being placed in the Yard will be made at its east end,

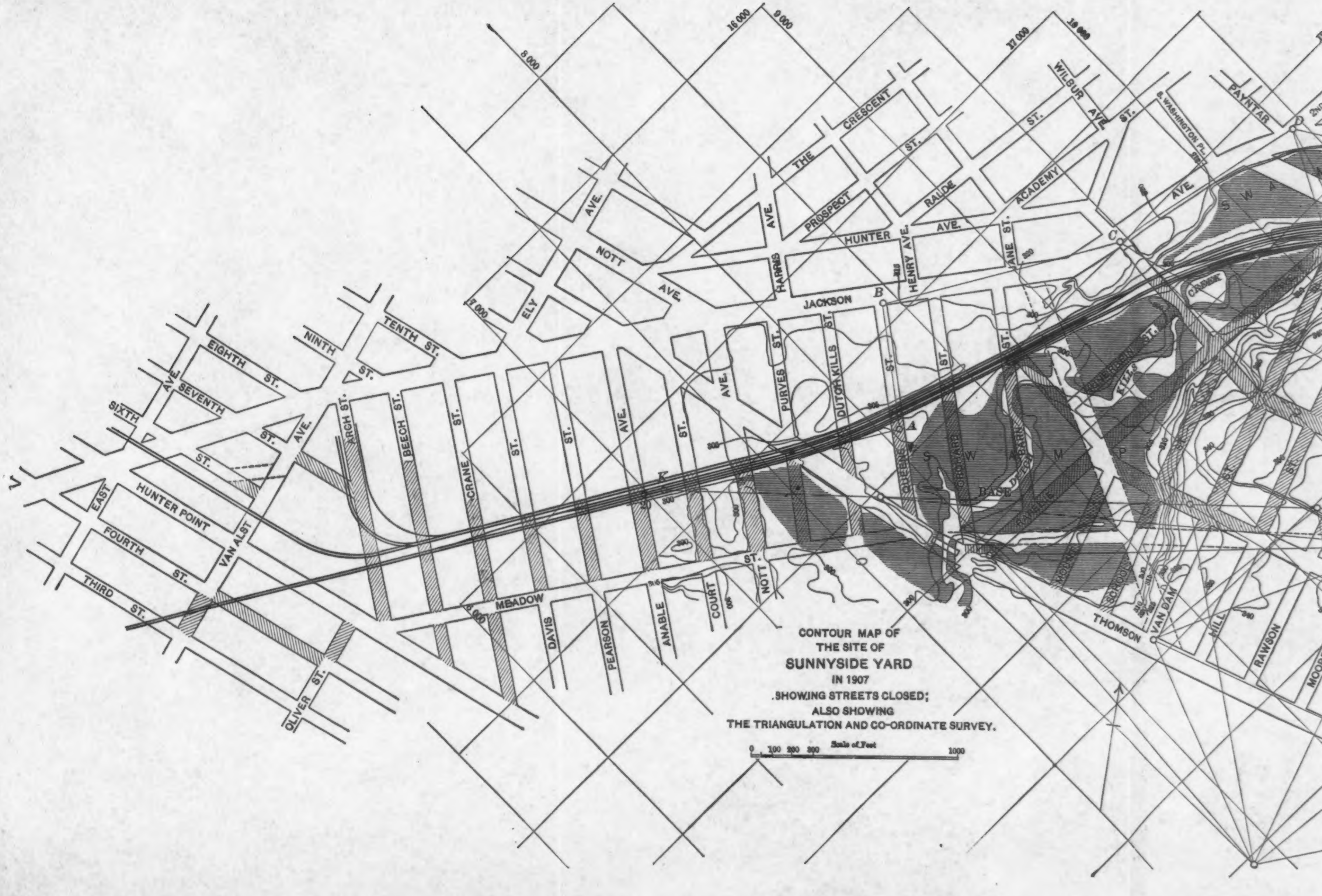
where four simultaneous movements may take place on tail-tracks provided for that purpose. This will leave the west end of the Yard free for the more important movements of the departing trains of empty cars to the New York Passenger Station. In order to avoid delay due to conflict of movements, it is further provided that in all cases the main tracks pass over the yard tracks by bridges.

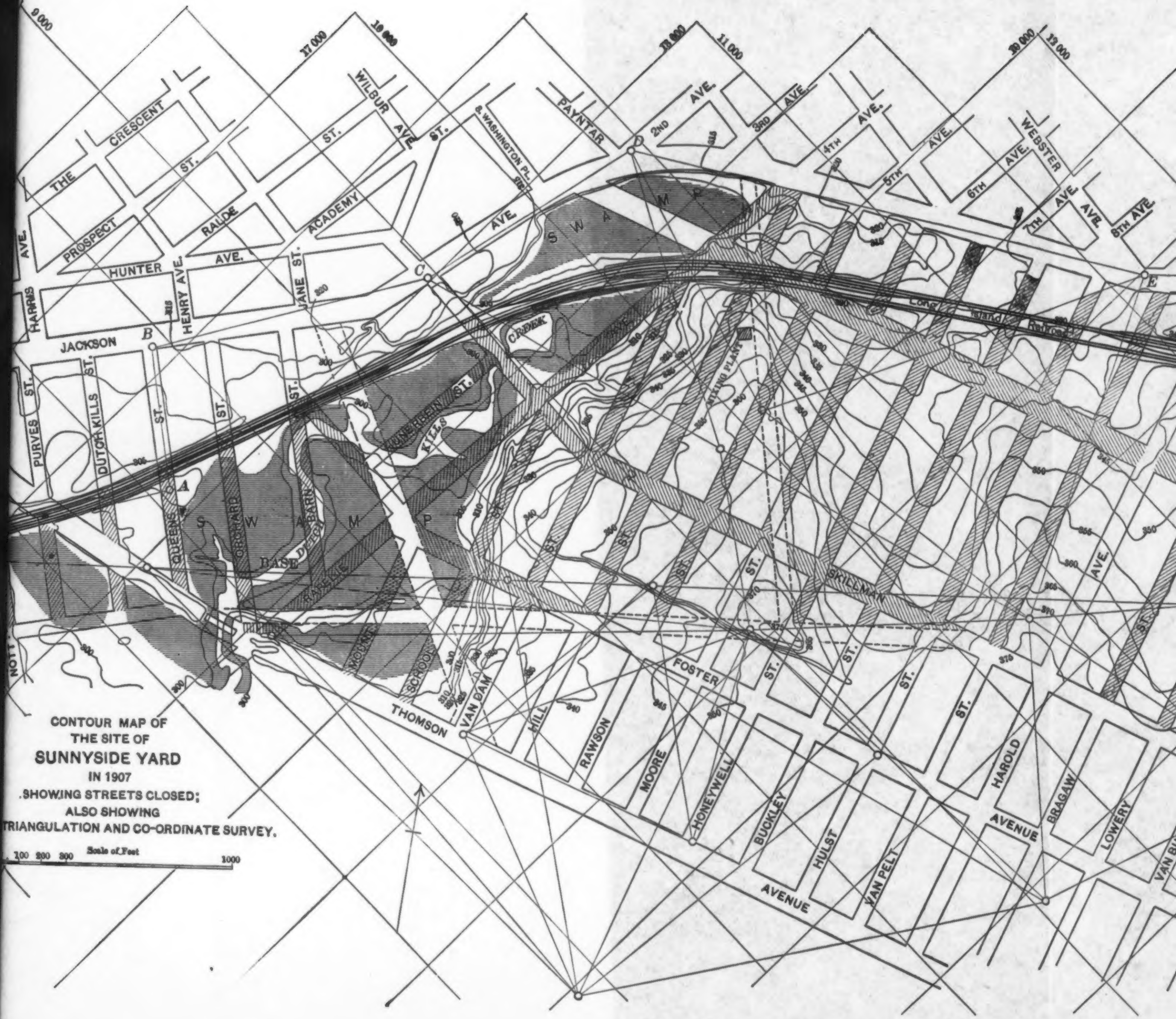
In the plans of Sunnyside Yard as well as in the work of construction throughout it, the possible future building of two additional lines, "E" and "F," leading from two tunnels under the East River connecting with 31st Street, Manhattan, has been kept in view, together with a possible future extension of the Yard near Harold Avenue as shown by dotted lines on Plate XLIII.

The capacity of the completed Yard will be as follows:

North Yard.—42 tracks, multiple-unit cars 62 ft. long..	526 cars.
South Yard.—45 tracks, Pullman cars and coaches 80 ft. long, with one electric locomotive 65 ft. long on each track	552 "
South Yard (dotted addition).—32 tracks, 50% 80-ft. cars and 50% 62-ft. cars........................	309 "
Total....................................	1 387 cars.

Originally, a swamp of 40 acres extended from the present location of Honeywell Street and Jackson Avenue to Thomson Avenue, and comprised a portion of the required Yard area; the remaining 168 acres within that area was rolling ground from 10 to 70 ft. above the swamp. Upon this high ground there were 246 buildings of all kinds, and these were purchased and torn down or removed. A view of the swamp in the early stages of the work is shown by Fig. 1, Plate XLV. A vegetable growth, of the nature of peat, from 1 to 4 ft. in thickness, formed the surface of the swamp, except in the bed of Dutch Kills Creek; beneath this there was a layer of mud, and in the bed of the stream a blue-black clay of the consistency of putty. As this muck and clay would move under the pressure of the filling over it, and produce waves of considerable height, it was specified in the contract that a blanket of earth about 4 ft. thick should be first placed over this part of the Yard area, in order to prevent this wave formation. This proved efficacious, except in one or two places, where,


CONTOUR MAP OF
THE SITE OF
SUNNYSIDE YARD
IN 1907
SHOWING STREETS CLOSED;
ALSO SHOWING
THE TRIANGULATION AND CO-ORDINATE SURVEY.
Scale of Feet
0 100 200 300 1000
THIRD ST.
FOURTH ST.
EAST
HUNTER POINT
VAN ALST
SIXTH
SEVENTH
EIGHTH ST.
NINTH
TENTH ST.
ARCH ST.
BEECH ST.
CRANE
DAVIS
PEARSON
ANABLE
COURT
NOTT
MEADOW
OLIVER ST.
ELY
NOTT AVE.
HARRIS
JACKSON
PURVES ST.
DUTCH KILLS
HENRY AVE.
HUNTER AVE.
PROSPECT
THE CRESCENT
RAUDE
JANE ST.
ACADEMY
WILBUR AVE.
PAYNTAR
QUEENS
ORCHARD
THOMSON
VAN DAM
SCHOOL
HILL
RAWSON
MOORE
SWAMP
BASE
CREEK
DUTCH KILLS



CONTOUR MAP OF
THE SITE OF
SUNNYSIDE YARD
IN 1907
SHOWING STREETS CLOSED;
ALSO SHOWING
TRIANGULATION AND CO-ORDINATE SURVEY.

PLATE XLIV.
TRANS. AM. SOC. CIV. ENGRS.
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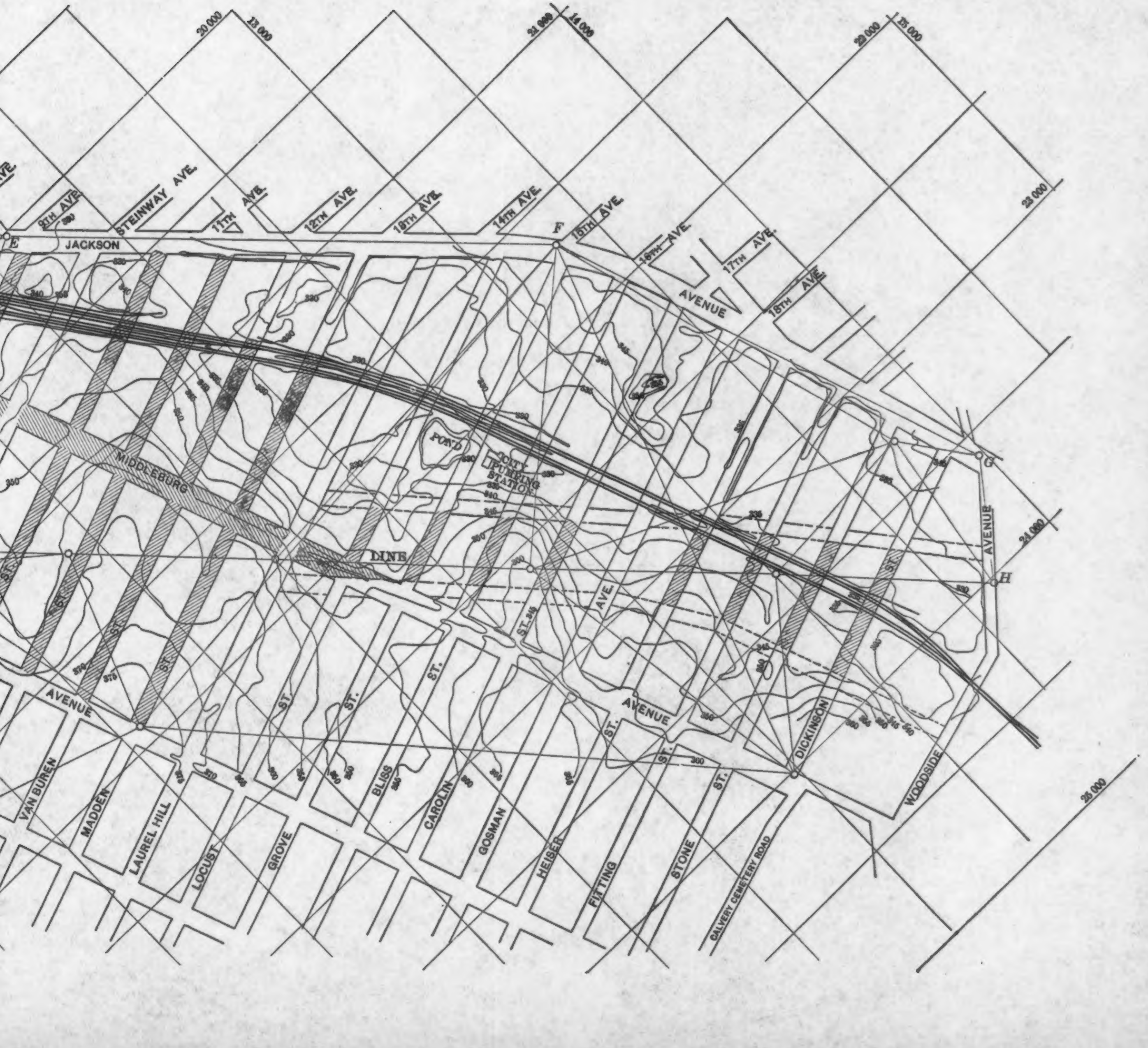


owing to unusual depth of filling, the wave formation broke through this covering and rose to such a height as to require excavation of the peat, muck, and mud, in order to secure proper track foundations. In the bed of Meadow Street, where the embankment was very high, the crest of one of the mud waves rose to an elevation of 28 ft. above the swamp. This mud wave is shown in Fig. 2, Plate XLV.

Plate XLIV, shows the contours of the Yard site in December, 1906, before any work was begun, also the location and extent of the swamp, and the location of the streets and railroad tracks at that time. The elevations on the contour and other maps and plans in this paper have reference to a datum elevation of 300, corresponding to the plane of reference, M. H. W. of the Rapid Transit Commission of New York City.

Survey of the Yard Site.

A system of co-ordinates, with origin 1 000 ft. south of, and 10 000 ft. west of, the northeast corner of 28th Street and First Avenue, Manhattan, had been established in connection with the East River tunnel work, and it was thought desirable that this same system be extended to embrace all the Sunnyside Yard area. To that end very accurate measurements, using a standardized steel tape, with a fixed pull, and calculating allowances for temperature and inclinations of the tape, were made at night from one of the established monuments of the tunnel survey line, thence along Jackson Avenue for 11 141.273 ft. to a point on Woodside Avenue. Check measurements, using a different tape, were then made back along the same line to the starting point. At each angle point a cemented iron-pipe monument was placed, and the angles were carefully read with a 10″ instrument, with from 5 to 10 repetitions. From the Woodside Avenue monument a working base line, 9 360.820 ft. long, was then established through the central part of the Yard. Owing to the houses obstructing the base line, and the difficulty of measuring over the swampy area and Dutch Kills Creek, points along the base line and on the south side of the Yard were determined by triangulation from the monumented line on Jackson Avenue. Using the co-ordinate system, equations were determined for the base line, bridge and street center lines, and for the principal track-tangents and curves, and proved of great value. The monumented line, base line, triangulation system, and co-ordinate

system are shown on Plate XLIV. At every 500-ft. point along the base line a large stake was placed; smaller intermediate 100-ft. stakes were set between them, and all were painted white. In order to avoid mistakes in identifying these smaller stakes, owing to the great number of stakes throughout the Yard, the corners of their square tops were cut as shown by Fig. 1, namely, one corner cut = 100 ft., two corners cut = 200 ft., etc.

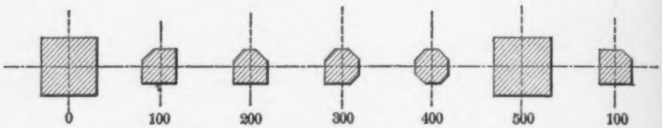


FIG. 1.

EXCAVATION.

Excavation was begun in December, 1906, and amounted to about 3 000 000 cu. yd. Notwithstanding the great amount of filling over the swamp and low ground, there was an excess of excavated material. Part of this excess was used by the Long Island Railroad in new construction work at near-by points and part by the Degnon Realty and Terminal Improvement Company in filling some of the swampy part of its property. The excavation consisted entirely of sand and gravel, with varying amounts of glacial deposit of water-worn gneiss, sandstone, and trap boulders. These boulders, while numerous and somewhat troublesome in places, formed on the whole a smaller portion of the excavation than was anticipated from surface indications. Nearly all that were suitable were broken and used in the concrete masonry. The only bed-rock exposures were in the bed of Dutch Kills Creek near the south abutment of Thomson Avenue Bridge and near Orchard Street, south of the Long Island Railroad tracks, but no rock excavation was found necessary except at the south abutment, and Piers Nos. 12 and 13 of Thomson Avenue Bridge, and for the sewer under the Long Island freight tracks on the north side of the Yard opposite Buckley Street. Under the swamp, the bed-rock was generally from 30 to 50 ft. below the surface. This depth was ascertained from wash-borings and by the length of the piles used. An abundance of clean, sharp, and reddish-colored sand was found in the general excavation throughout the Yard. This sand, when tested with cement, gave a stronger mortar than the Hempstead Harbor sand (the New York

FIG. 1.—VIEW OF 40-ACRE SWAMP NOW FORMING PART OF SUNNYSIDE YARD.

FIG. 2.—MUD WAVE, 28 FT. HIGH, IN SWAMP.

FIG. 1.—EXCAVATION FOR SOUTH YARD.

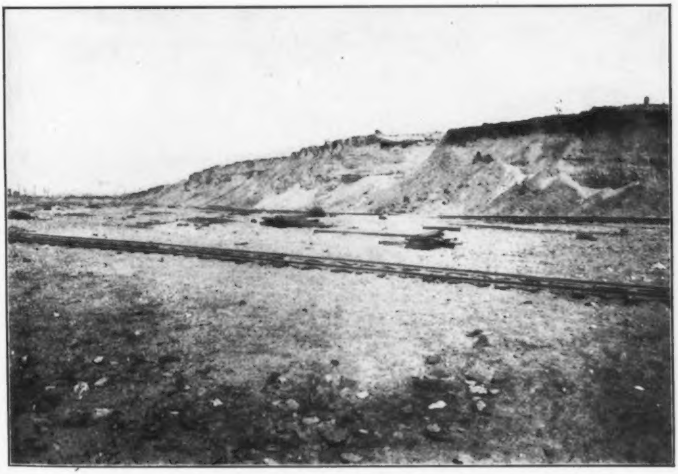


FIG. 2.—EXCAVATION FOR SOUTH YARD.

City standard sand) and, therefore, it was used in all bridge and sewer work. In constructing the sewer along the north side of the Yard between Moore and Buckley Streets, a very fine, whitish, quicksand was encountered, and gave considerable trouble. This sand was so fine that 70% would pass through a No. 200 sieve.

Figs. 1 and 2, Plate XLVI, and Fig. 1, Plate XLVII, show the depth of excavation and the character of the materials in different parts of the Yard.

Water in very large quantities was encountered in almost all excavations for masonry foundations westward from Laurel Hill Avenue, and in some foundations it became necessary to pump as much as 400 gal. per min. This ground-water stood at Elevation 324 at Laurel Hill Avenue, sloping gradually to 310 in the high ground near the swamp. Over the swamp area the water elevation was about 300.

The Degnon Realty and Terminal Improvement Company, of New York City, was the contractor for the excavation, and for the bridge and sewer masonry. In the work of excavation the contractor's plant varied: At its maximum it consisted of 3 Bucyrus and 1 Thew steam shovels, 11 narrow-gauge locomotives, 150 4-yd. dump-cars, and about 10 miles of track. The maximum excavation for one shovel for one 10-hour day was 3 500 cu. yd., in April, 1908. The maximum excavation for one shovel for one month was 60 615 cu. yd., in January, 1909. Owing to the difficulty of lighting the work properly, but little shovel excavation was done after dark.

Masonry.

All masonry is of concrete except in the buildings above the foundations and in sewer manholes, where brick was used. The concrete in the bridge piers, abutments, and retaining walls was composed of 1 part cement, 3 parts sand, and 6 parts broken stone. In sewers the proportion was $1:2\frac{1}{2}:5$, and in bridge floors, $1:2:4$. The size of stone used in the first case was between $\frac{3}{8}$ and $2\frac{1}{4}$ in., in the second case between $\frac{3}{8}$ and 1 in., and in the third between $\frac{3}{8}$ and $1\frac{1}{4}$ in., ring measurement.

Where concrete masonry exceeded 5 ft. in thickness, the use of large stones was permitted up to 25% of the total volume of the masonry. The stones were placed at least 6 in. apart at every point and not nearer than 12 in. to the faces of the masonry.

Four Ransome concrete mixers were used in the general contract work. Three of these mixers were placed at the crusher plant near Honeywell Street. This crusher plant, Fig. 2, Plate XLVII, contained one No. 4 and one No. 6 Gate's crushers, together with stone- and sand-hoisting belts and the necessary storage bins. From these mixers to points within about 3 000 ft., the concrete was transported in 1-yd., square-bottom dump-buckets placed on narrow-gauge cars and hauled by narrow-gauge locomotives. For distances greater than 3 000 ft., a mixer was erected at the site of the work, as it was found that after hauling the mixture about that distance it began to separate. In order to secure a uniform finish, the exposed faces of the concrete masonry, as a general rule, had a facing of mortar 2 in. thick deposited simultaneously with the concrete and separated from it by metal diaphragms which were removed immediately, and the excess mortar spaded into the concrete. Above the foundations of the abutment and pier masonry, the concrete was laid continuously to completion. By this method, not only a perfect monolithic structure was obtained, but the formation of all unsightly joints between the different days' work was prevented. Expansion joints were placed about 50 ft. apart in all abutments and piers above the foundations.

Reinforcing bars of twisted, square section were placed in the floors of the bridges and buildings, but in the bridge masonry, sewers, pipe-tunnel, and pipe-trenches, some of both the twisted and corrugated bars, together with expanded metal, were used.

Plates XLVIII, XLIX, L, and Fig. 1, Plate LI, show various pieces of masonry in different stages of construction.

Bridges.

The highway bridges crossing over the Yard are all of the deck plate-girder type. They were made to conform to the layout of the tracks in the Yard, and, therefore, required a great diversity of lengths of spans and irregularity in pier alignment. In order to secure a minimum clearance of 16½ ft. above the top of rails, it was necessary in several cases to introduce girders of shallow depth. Between the abutments the girders are supported on steel columns resting on and anchored to concrete piers. The columns are of a built **H**-section composed of four angles and two channels, and where they are adjacent to running tracks, they have concrete protection for about 6 ft. above the rails.

FIG. 1.—EXCAVATION FOR LOOP TRACKS.

FIG. 2.—CRUSHER, AND CONCRETE MIXING PLANT.

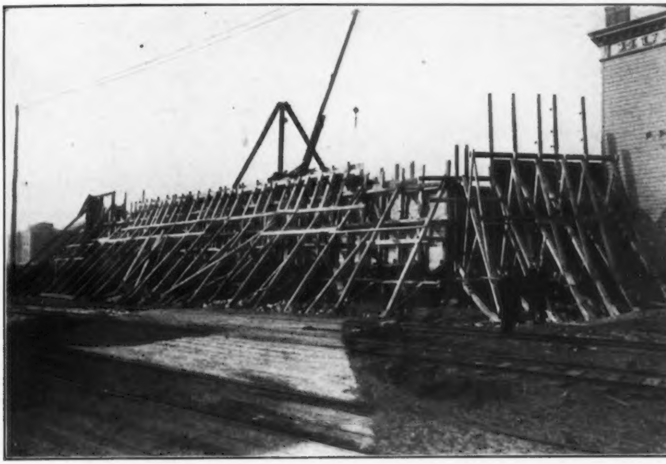
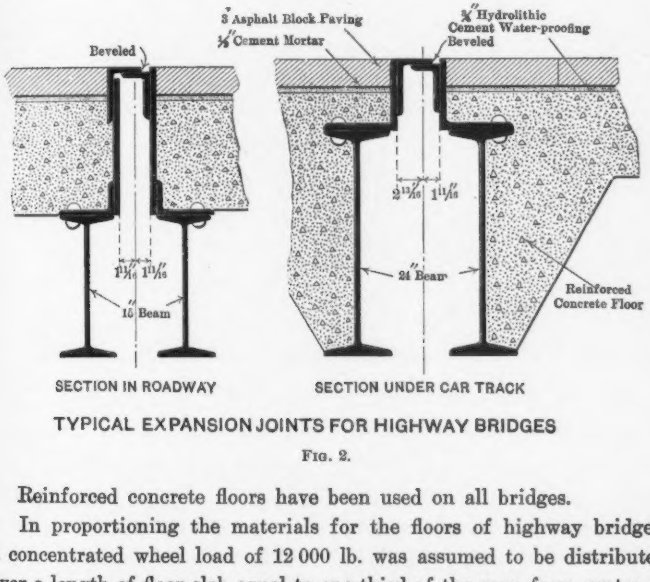


FIG. 1.—FORM WORK FOR MASONRY OF NORTH ABUTMENT, THOMSON AVE. BRIDGE.

FIG. 2.—THOMSON AVE. BRIDGE: MASONRY OF NORTH ABUTMENT ABOUT COMPLETED.

The flange stress in the girders was calculated not to exceed 13 000 lb. per sq. in., no allowance being made for impact. The web plates are generally ⅜ in. thick, except where heavier metal was required to give sufficient bearing area for rivets. Expansion joints (cross-sections of which are shown by Fig. 2), are provided at intervals of about 150 ft. Provision has been made for double-track street-car lines on all bridges, but the rails are not yet laid. A typical panel of hand-railing is shown by Fig. 3.

In some cases where bridges pass over freight tracks which will be operated for a time by steam locomotives, a number of the girders are encased in concrete to prevent destructive smoke action.



TYPICAL EXPANSION JOINTS FOR HIGHWAY BRIDGES

FIG. 2.

Reinforced concrete floors have been used on all bridges.

In proportioning the materials for the floors of highway bridges, a concentrated wheel load of 12 000 lb. was assumed to be distributed over a length of floor slab equal to one-third of the span from center to center of the girder, plus an additional length equal to the thickness of the slab.

The extreme fiber stress on concrete in compression was assumed not to exceed 500 lb. per sq. in., and the shearing stress 50 lb. per sq. in. The tensile stress allowed in the reinforcing steel rods was 16 000 lb. per sq. in.

To insure the longitudinal distribution of the load as assumed, and to guard against shrinkage cracks, longitudinal reinforcing rods were used having an aggregate net section equal to 50% of the aggregate net section of the transverse reinforcement.

Within 24 hours after the floor concrete was placed in the driveway portion of these bridges, a ¾-in. covering of Hydrolithic water-proof cement was spread over them, and a granolithic finish, 1 in. thick, was placed on the sidewalks. Asphalt paving blocks, 3 in. thick, were laid on the driveway on ½ in. of 1 : 3 cement and sand mortar mixed with a small proportion of water.

Fig. 4 shows typical cross-sections of the highway bridges.

Thomson Avenue Bridge.—All masonry in this bridge is on piles, with the exception of the south abutment, Pier No. 13, and part of Pier No. 12, which are on rock, and a small part of the north approach wall which is on earth foundation. Batter piles were used under the north abutment and the high retaining walls of the north approach. A city water pipe, 16 in. in diameter, had been placed in Thomson Avenue prior to the inception of the Tunnel Company's work. Where it crossed the pier sites it was built into the masonry. The danger of breaking, due to the weight of the embankment to be built over it, made it necessary to replace the pipe by a new one to be carried on the bridge superstructure. The diameter of this pipe was increased to 20 in. at the request of the City. As the depth of the girders in several spans was not sufficient to provide for suspending this pipe below the floor in a satisfactory manner, it was decided to let it rest on the deck of the bridge and occupy a part of the sidewalk. In order to overcome the effect on the pipe if laid directly on the bridge, due to the bridge expansion, and to avoid the use of expansion pipe-joints, the pipe was suspended in saddle supports, as shown by Fig. 5. This method has proved satisfactory.

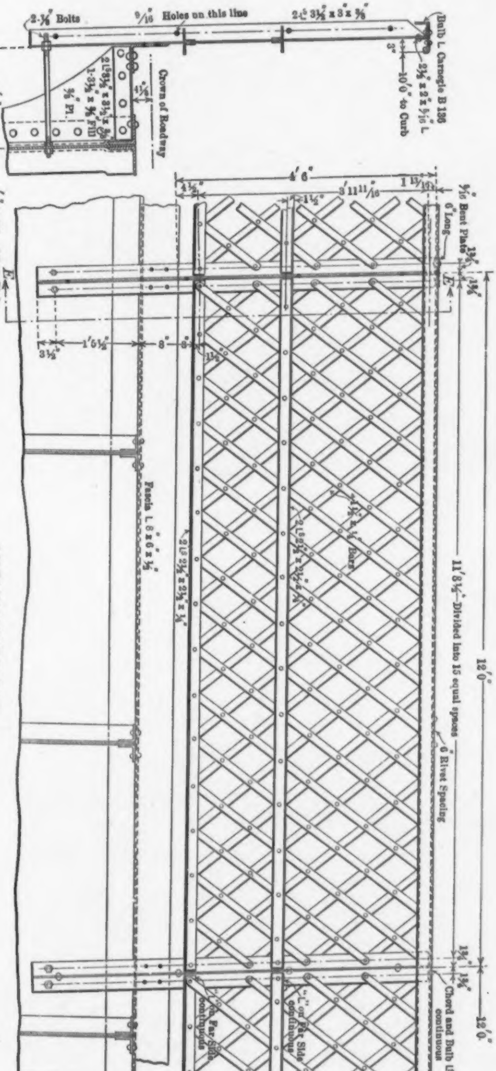
Bridge Approach Viaduct.—All the masonry of this bridge is on piles, except the south abutment, which is on a filled sand foundation. As a number of the girders were of insufficient depth to carry the city water pipes below the floor, a width of 3 ft. 6 in. was added on both sides of the bridge, outside of the hand-rail, for that purpose.

Honeywell Street and Harold Avenue Bridges.—The piers and abutments of these bridges are on sand and gravel foundations without piles. A 12-in. City water pipe is supported on 2½ by ⅜-in. strap-hangers

FIG. 1.—BRIDGE NO. 5: MASONRY READY FOR SUPERSTRUCTURE.

FIG. 2.—BRIDGE NO. 4: MASONRY READY FOR SUPERSTRUCTURE.

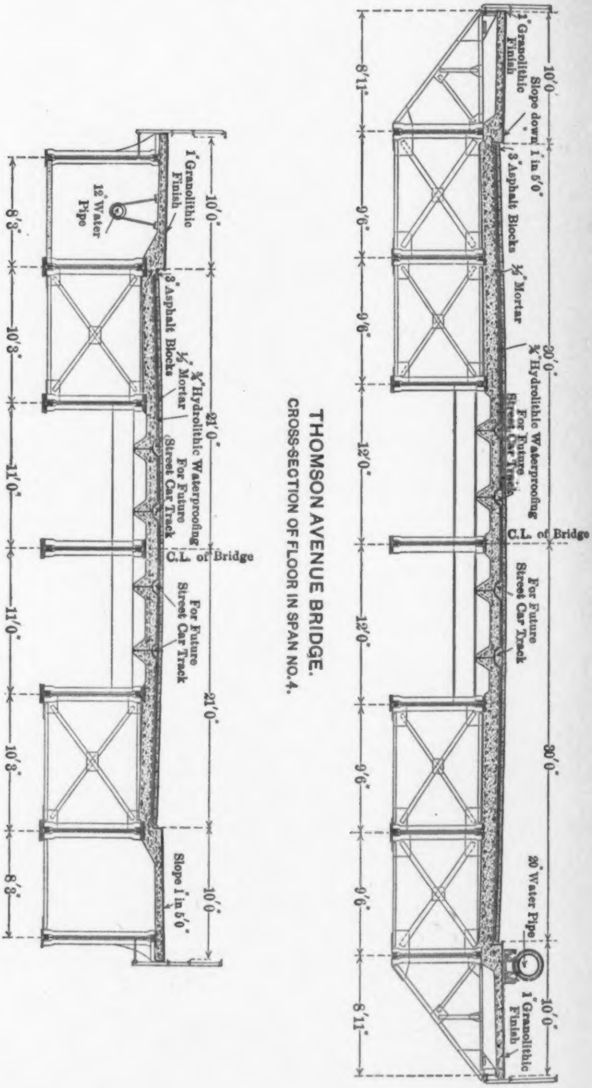
FIG. 3.—BRIDGE NO. 4 ABOUT COMPLETED.



SECTION *EE*

HIGHWAY BRIDGE
TYPICAL PANEL OF HAND-RAILING

FIG. 3.



THOMSON AVENUE BRIDGE.
CROSS-SECTION OF FLOOR IN SPAN NO. 4.

HONEYWELL STREET BRIDGE.
TYPICAL CROSS-SECTION.

FIG. 4.

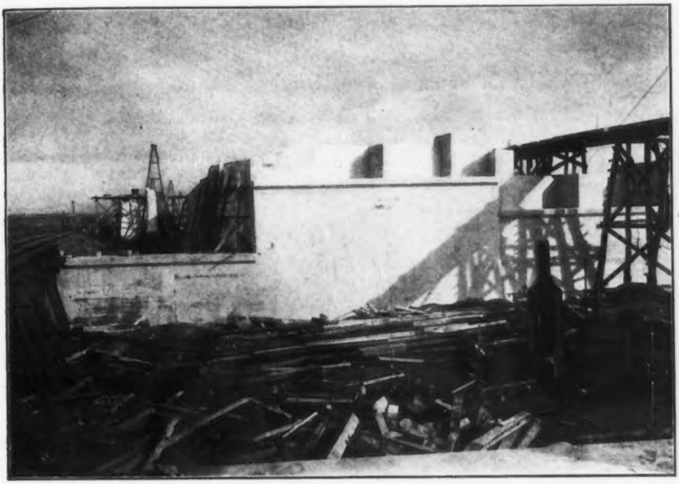


FIG. 1.—GOSMAN AVE. BRIDGE: MASONRY UNDER CONSTRUCTION.

FIG. 2.—BRIDGE NO. 2: MASONRY UNDER CONSTRUCTION.

beneath the sidewalk, as shown by the cross-section of Honeywell Street Bridge, Fig. 4. These are sufficiently flexible to allow of considerable movement of the bridge at the expansion joints without affecting the pipe. In the case of Honeywell Street Bridge, however, which is 1 574 ft. long, two expansion pipe-joints were introduced.

Longitudinal elevations of the Bridge Approach Viaduct and Honeywell Street Bridge, together with cross-sections of the Yard are shown by Plate LII.

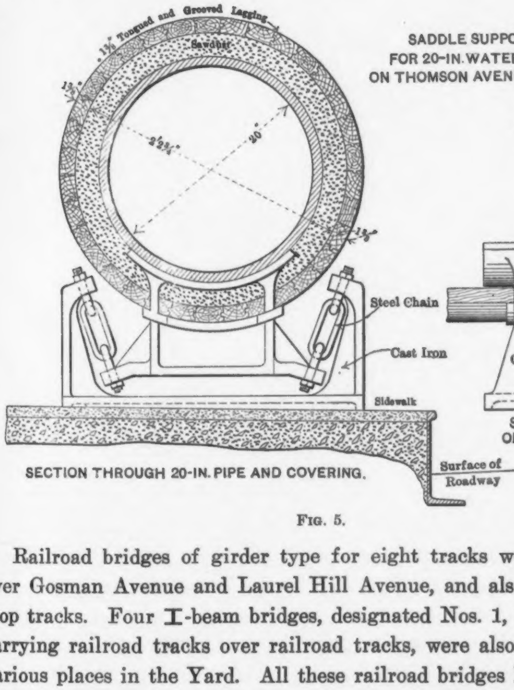


FIG. 5.

Railroad bridges of girder type for eight tracks were constructed over Gosman Avenue and Laurel Hill Avenue, and also over the four loop tracks. Four I-beam bridges, designated Nos. 1, 2, 4, and 5, for carrying railroad tracks over railroad tracks, were also constructed at various places in the Yard. All these railroad bridges have reinforced concrete floors, and have been made water-proof with seven coats of pitch and six layers of felt, protected by one course of brick laid in cement mortar. Fig. 2, Plate LI, Plate LIII, and Fig. 1, Plate LIV, show some of the highway and railroad bridges under construction. The general dimensions, and the quantities of materials used in the construction, of each highway and railroad bridge, are given in Tables 1 and 2.

TABLE 1.—HIGHWAY BRIDGES OVER SUNNYSIDE YARD: DIMENSIONS AND QUANTITIES OF MATERIALS.

Name of bridge.	Length, in feet.	Number of spans.	Roadway, width in feet.	Sidewalks, width in feet.	Total width of bridge, in feet.	Structural steel in superstructure, in pounds.	Steel reinforcing bars in floor, in pounds.	Steel reinforcing bars in protective piers, in pounds.	Steel reinforcing bars in substructure, in pounds.	Total steel, in pounds.	Concrete in floor, in cubic yards.	Concrete in protective piers, in cubic yards.	Concrete in substructure, in cubic yards.	Total concrete, in cubic yards.	Piles, total length, in feet.	Contractors for superstructures.
Thomson Ave.......	773	14	60	10	80	3 346 235	252 580	40 762	10 492	3 650 069	2 805	1 409	21 602	25 816	97 041	Pennsylvania Steel Company.
Bridge approach....	1 036	19	60	10	87	4 682 434	309 074	19 347	6 213	5 017 068	2 889	686	8 593	12 168	68 141	McClintic-Marshall Construction Company.
Honeywell St........	1 574	22	42	10	62	6 998 271	353 704	11 709	153	7 363 837	3 540	396	4 314	8 250	....	American Bridge Company.
Driveway to yard...	310	6	20	....	20											
Harold Ave. north..	361	7	42	10	62	3 128 657	151 729	17 391	1 171	3 298 948	2 059	577	4 436	7 072	....	Lewis F. Shoemaker and Company.
" " south..	528	9	42	10	62											
Total...........	......	..	....	....	....	18 155 597	1 067 087	89 209	18 029	19 329 922	11 293	3 068	38 945	53 306	165 182	

FIG. 1.—BRIDGE NO. 2: MASONRY UNDER CONSTRUCTION.

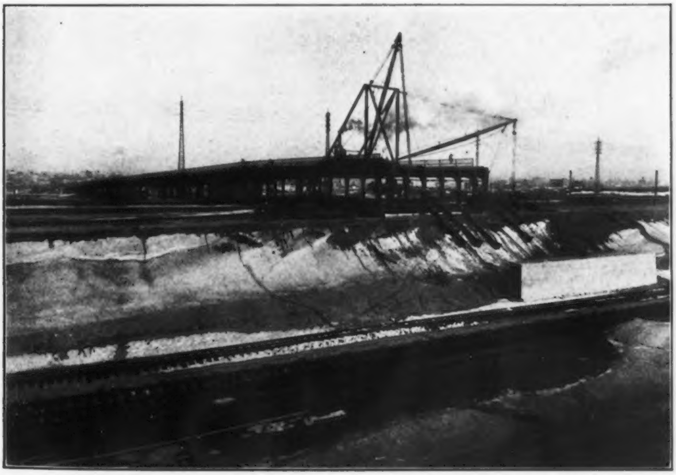


FIG. 2.—ERECTING SUPERSTRUCTURE, HONEYWELL ST. BRIDGE.

TABLE 2.—RAILROAD BRIDGES, SUNNYSIDE YARD: DIMENSIONS AND QUANTITIES OF MATERIALS.

Name of bridge.	Type of bridge.	Maximum length, in feet.	Number of spans.	Number of tracks.	Structural steel in superstructure, in pounds.	Steel reinforcing bars in floors, in pounds.	Steel reinforcing bars in protective piers, in pounds.	Steel reinforcing bars in substructure, in pounds.	Total steel, in pounds.	Concrete in floor, in cubic yards.	Concrete in protective piers, in cubic yards.	Concrete in substructure, in cubic yards.	Total concrete, in cubic yards.	Piles, total length, in feet.	Contractors for superstructures.
No. 1..........	I-beam........	96.5	1	1	76 200	3 350	....	12 250	91 800	235	....	4 600	4 835	......	Wilson and English Construction Company.
No. 2..........	" "	283.0	2	2	426 193	22 011	....	93 500	541 704	986	....	11 133	12 119	......	McClintic-Marshall Construction Company.
No. 4..........	" "	172.0	2	2	181 899	10 515	....	39 897	232 311	539	....	5 156	5 695	......	McClintic-Marshall Construction Company.
No. 5..........	" "	103.0	2	2	141 137	4 867	....	24 560	170 564	367	....	3 773	4 140	20 118	McClintic-Marshall Construction Company.
Laurel Hill Ave........	Deck girders, half-through girders......	188.5	4	8	1 643 142	103 600	191	25 596	1 772 529	810	19	6 742	7 571	......	McClintic-Marshall Construction Company.
Gosman Ave.	Deck girders, half-through girders......	108.5	3	8	1 005 796	50 422	269	10 381	1 066 868	517	20	5 339	5 876	......	McClintic-Marshall Construction Company.
Total.....	....	......	....	....	3 474 367	194 765	460	206 184	3 875 776	3 454	39	36 743	40 236	20 118	

NOTE.—Quantities of materials shown for Bridge No. 1 are approximate.

Tracks.

In the final plan of the tracks between Thomson Avenue and Woodside Avenue, exclusive of the Yard addition shown in dotted lines, and the Long Island Railroad freight tracks north of the Yard, there are:

13.56 miles of main tracks.
39.62 miles of yard and yard-running tracks.

53.18 total miles of tracks.

285 No. 8 frogs.
13 No. 10 frogs.
7 No. 12 frogs.
35 No. 15 frogs.
1 double slip.

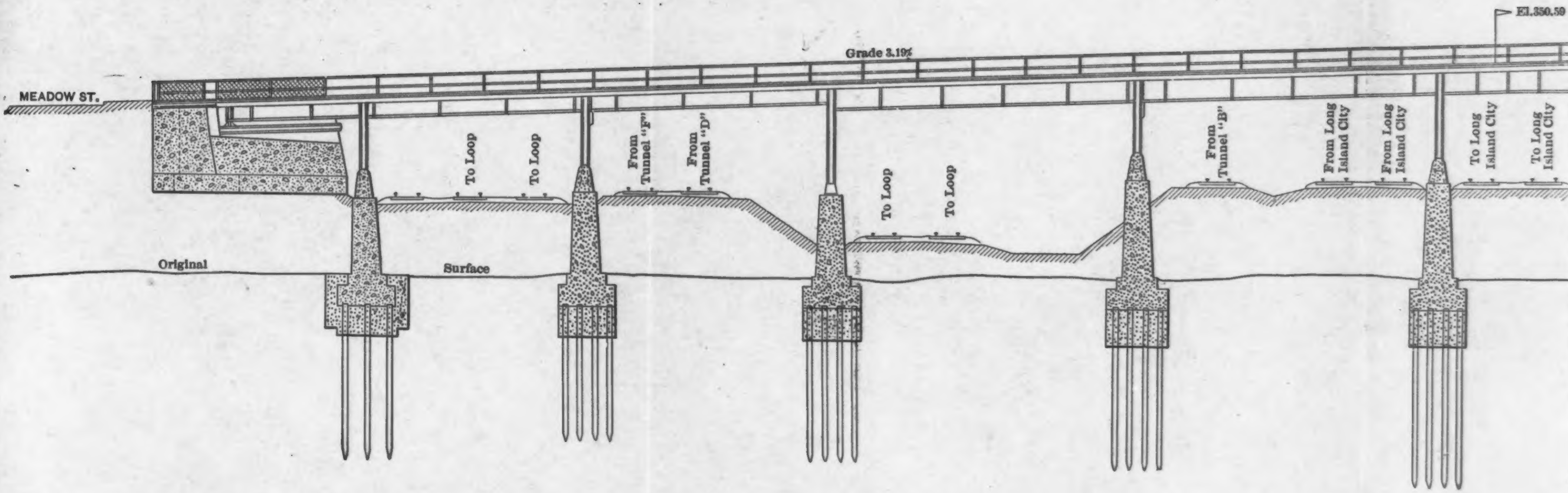
The main tracks and loop tracks are laid with 100-lb. rails supported on oak ties, with tie-plates. The yard and yard-running tracks are laid with 85-lb. rails on yellow pine ties, with tie-plates. Each track throughout the Yard has a parallel third-rail for supplying electric motive power.

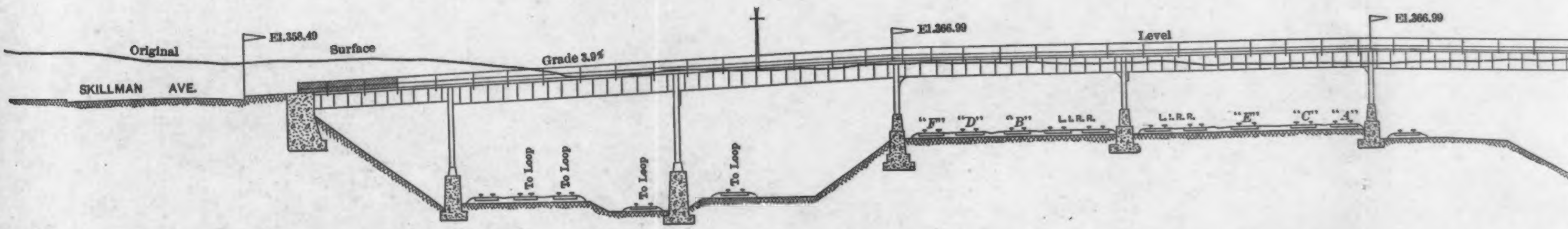
An electric-pneumatic interlocking system has been installed at four points, and the necessary signal cabins and signals have been erected.

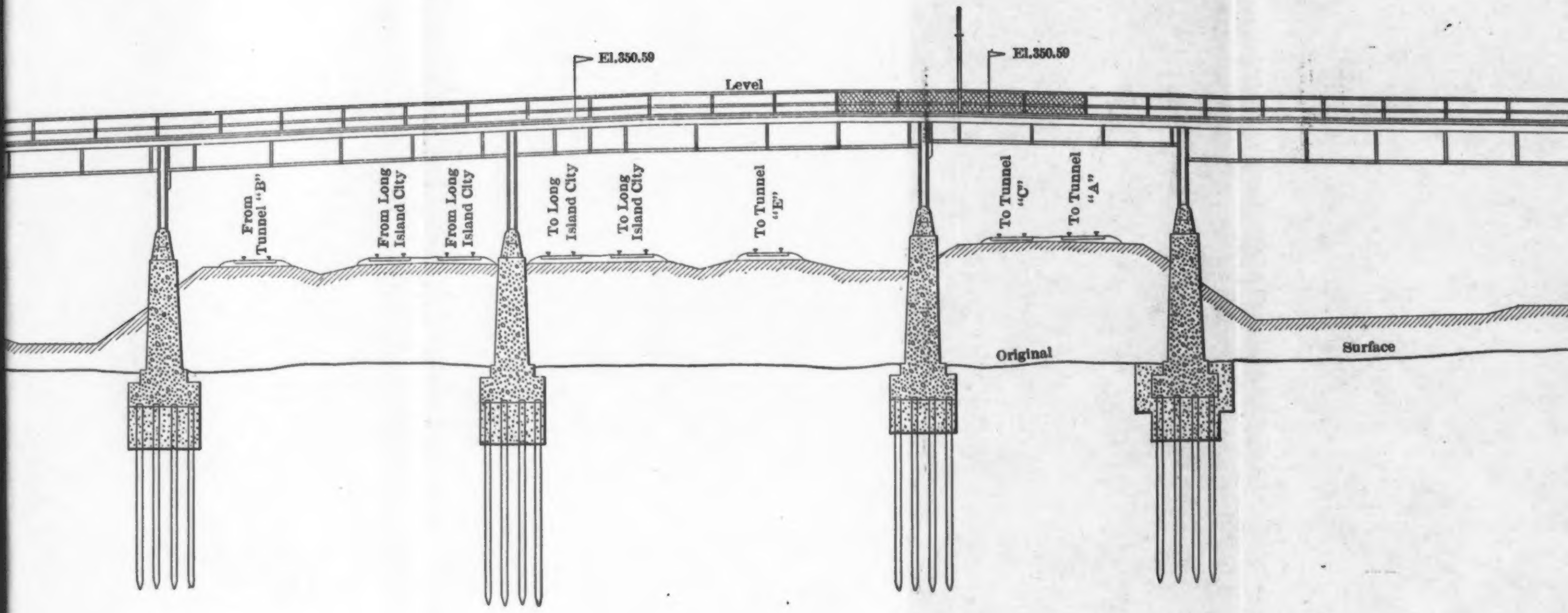
Buildings.

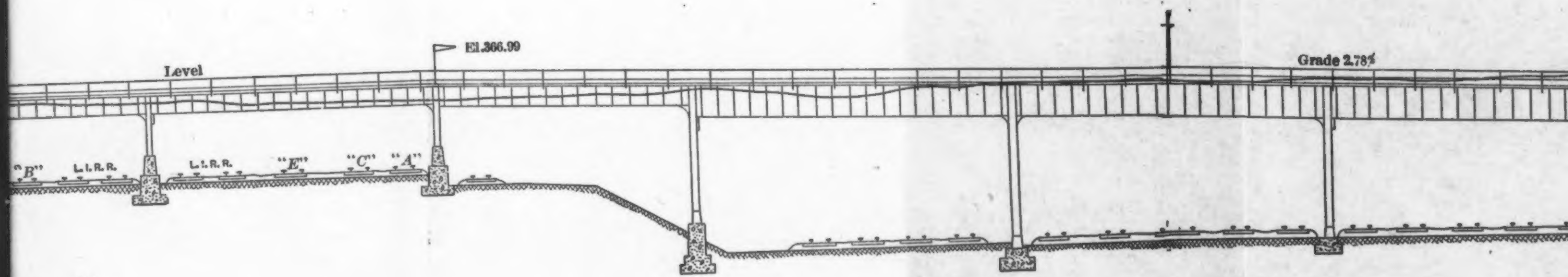
In order to accommodate the necessary stores and plant required for the Yard, the following buildings have been erected under contract with the John W. Ferguson Company, of Paterson, N. J.:

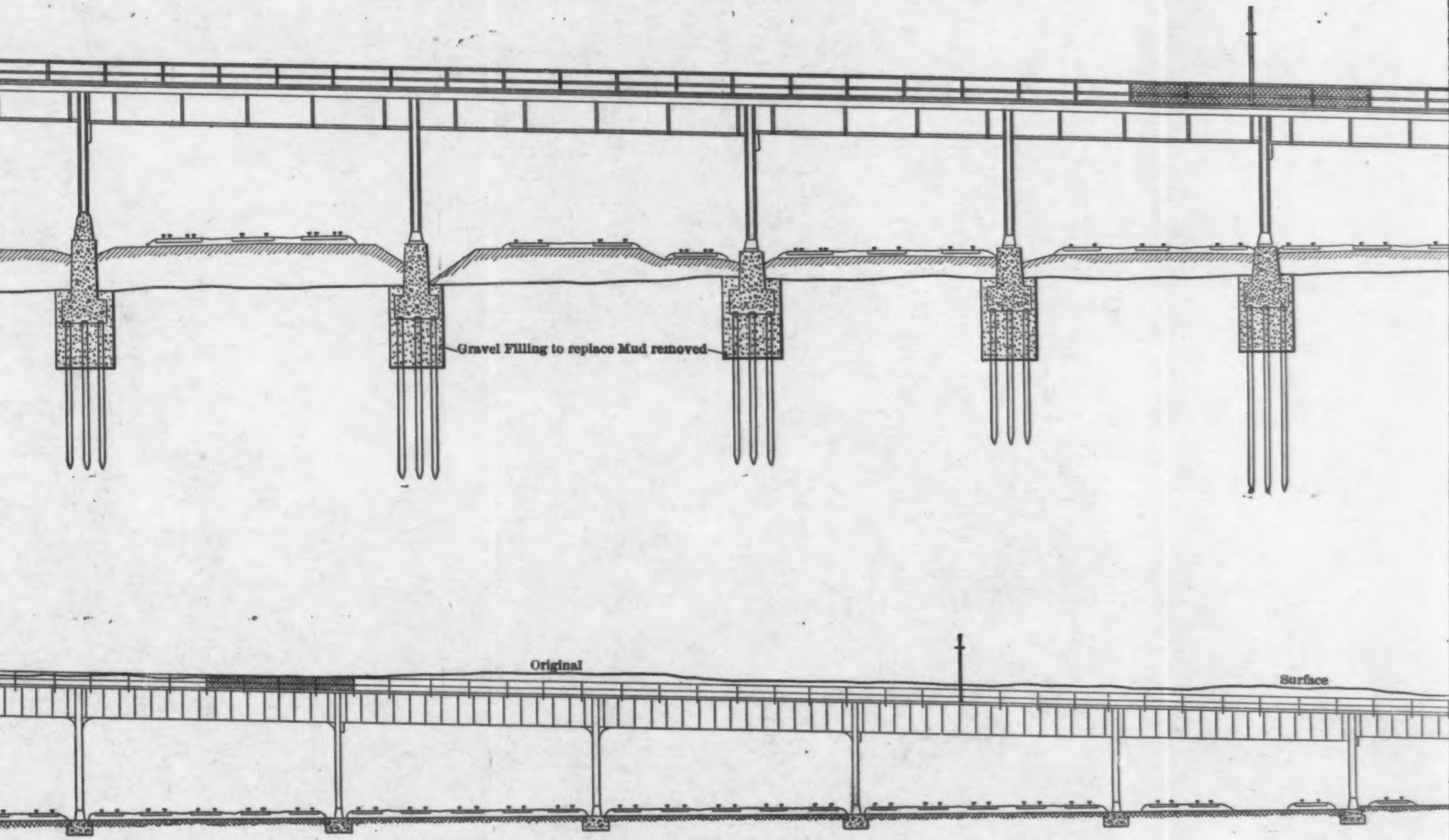
Stores and Commissary Building	258 ft.	by	67 ft.
Stores and Lavatory Building	162 ft.	"	67 ft.
Oil- and Lamp-House	67 ft.	"	51 ft.
Sand-House	32 ft.	"	25 ft.
Battery-Repair Building	103 ft.	"	67 ft.
Inspection Building	96 ft.	"	47 ft.
Boiler-House and Sub-station	233 ft.	"	51 ft.
Machine and Smith Shop	80 ft.	"	40 ft.
Inspection-Pit Shed	100 ft.	"	50 ft.
Three Signal Cabins	27 ft.	"	17 ft.
One Signal Cabin and Yard Building	84 ft.	"	14 ft.
Carpet Shed	88 ft.	"	33 ft.


El. 350.59
Grade 3.19%
MEADOW ST.
To Loop
To Loop
From Tunnel "F"
From Tunnel "D"
To Loop
To Loop
From Tunnel "B"
From Long Island City
From Long Island City
To Long Island City
To Long Island City
Original
Surface

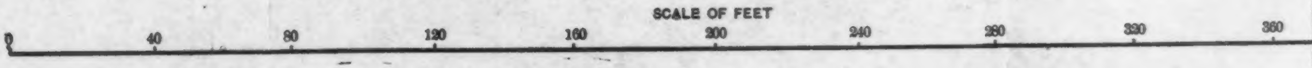

El. 358.49
Original
Surface
SKILLMAN AVE.
Grade 3.9%
El. 366.99
Level
El. 366.99
"F"
"D"
"B"
L.I.R.R.
L.I.R.R.
"E"
"C"
"A"
To Loop
To Loop
To Loop
To Loop

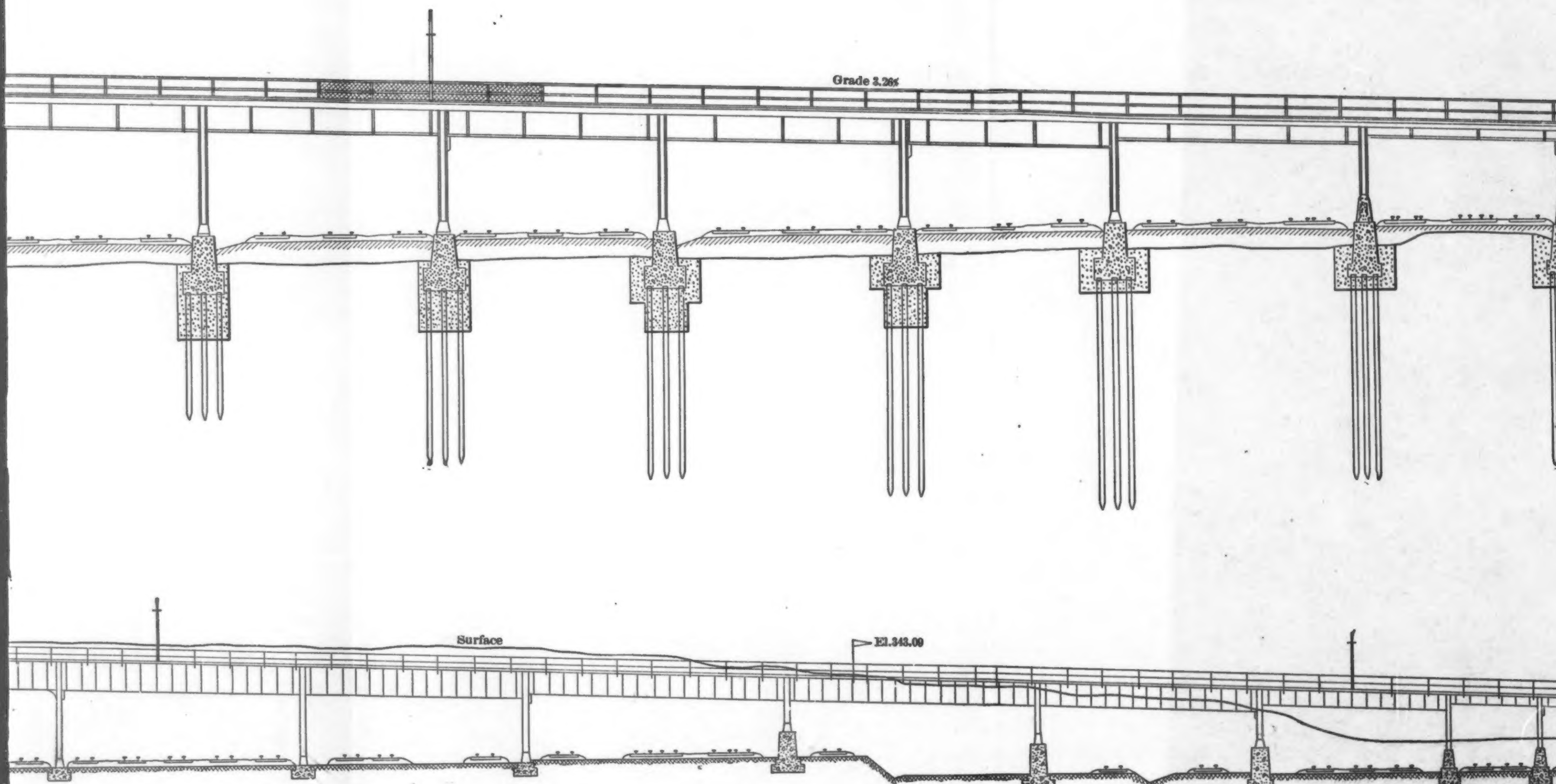

El.350.59
El.350.59
Level
From Tunnel "B"
From Long Island City
From Long Island City
To Long Island City
To Long Island City
To Tunnel "E"
To Tunnel "C"
To Tunnel "A"
Original
Surface


El.366.99
Level
Grade 2.78%
"B"
L.I.R.R.
L.I.R.R.
"E"
"C"
"A"



SKETCH SHOWING ELEVATION OF HONEYWELL STREET BRIDGE





ATION OF HONEYWELL STREET BRIDGE

SCALE OF FEET

200 240 280 320 360 400

PLATE LII.
TRANS. AM. SOC. CIV. ENGRS.
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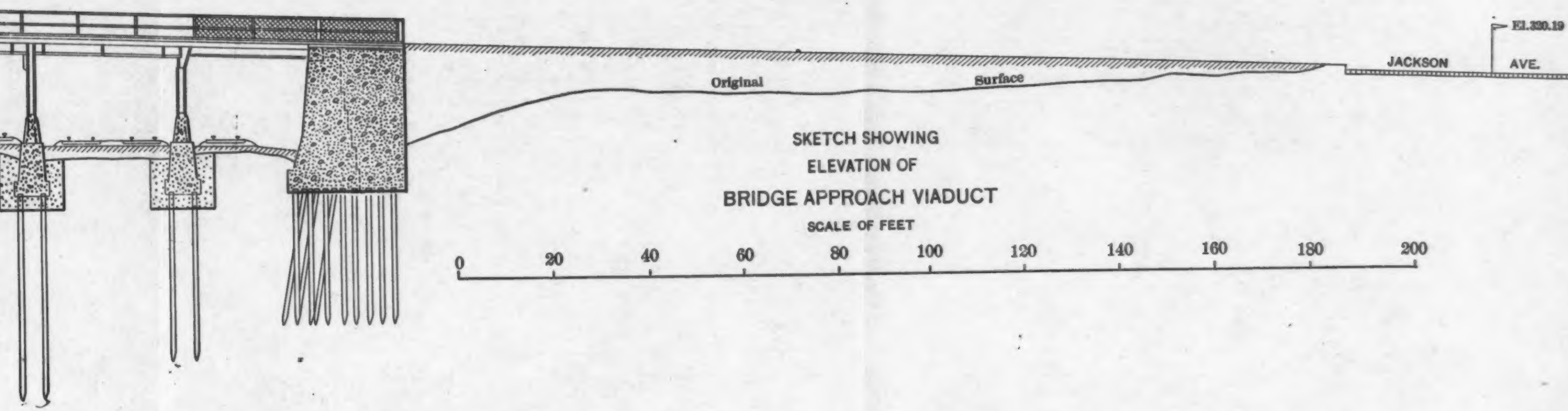
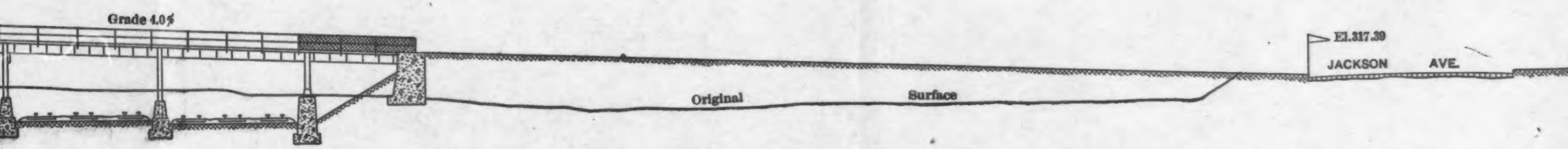
PENNSYLVANIA R. R. TUNNELS: THE SUNNYSIDE YARD.



SKETCH SHOWING
ELEVATION OF
BRIDGE APPROACH VIADUCT
SCALE OF FEET



All these buildings have steel frames and roofs, and brick walls, except the Inspection Building and the Machine and Smith Shop with plaster walls, and the Carpet Shed and the Inspection-Pit Shed with corrugated-iron sides. All buildings have concrete foundations.

The portion of the Stores and Commissary Building located over the swamp is supported on Chenoweth concrete piles, made by rolling woven wire of small mesh, reinforcing rods, and very dry concrete into a cylinder about 14 in. in diameter. A double water-jet and a pile-driver with a cushioned hammer weighing 4 600 lb. and having a maximum fall of 4 ft., were used in driving these piles. Two of the Signal Cabins are supported on wooden piles.

A brick-lined, steel stack, 200 ft. high, 12 ft. 8 in. at the bottom and 9 ft. 10 in. at the top (outside diameter), has been erected at the Boiler-House. Steel Umbrella Sheds, 20 ft. wide and having an aggregate length of 2 798 ft., have been erected between the tracks adjacent to the buildings. Fig. 2, Plate LIV, is a general view of the buildings as constructed.

Sewers.

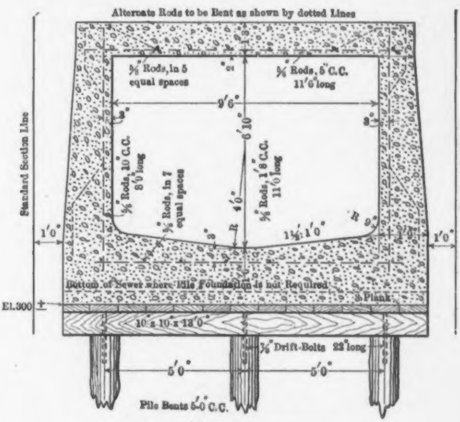
The slope and shape of the Yard caused the surface drainage to flow toward the tunnel portals, and it was necessary to intercept it by an adequate sewerage system before it reached these points. Two places of discharge have been used, and two sewer systems constructed: One system receives nothing but surface drainage, and empties into Dutch Kills Creek, the other receives both house sewage and surface drainage, and empties into the Webster Avenue sewer system at Payntar Avenue and Jackson Avenue. In some low parts of the Yard open-jointed sub-surface tile drains were used. As far as practicable, sewers were located so as to avoid the use of piles, but, across the swamp, both the concrete and iron-pipe sewers (except some of small section), are thus supported. When in close proximity to, or directly under, railroad tracks, the concrete sewers were increased in strength by additional reinforcement. The largest sewer is of square section, 9 ft. 6 in. by 6 ft. 10 in., Fig. 1, Plate LV, and Fig. 6.

Fig. 7 shows plans and sections of sewers as constructed.

Water Supply.

To supply the great quantity of water required for the power-station and for Yard use, a number of wells, about 10 ft. square, from 30 to

40 ft. deep (equal to from 50 to 80 ft. below the original surface of the ground), were sunk through the sand and gravel in different parts of the Yard. After pumping from them continuously, night and day, for one week, their capacity and the quality of the water were ascertained. The results having proved satisfactory in both respects, it was decided to use the water from one of the wells near Harold Avenue for all purposes of the Company in Long Island City. This well is 7 ft. 6 in. in diameter, and is lined with reinforced concrete, 1 ft. thick, supported on short piles driven below the bottom of the well. A test indicated that its maximum capacity was about 800 000 gal. per day. The pump will be placed in the Boiler-House, 2 347 ft. from the well.



SECTION OF 9'6" CONCRETE SEWER ON PILES

FIG. 6.

PIPE TUNNEL AND TRENCHES.

On account of the great number of water, steam, gas, and air pipes throughout the Yard, it was decided to place them in concrete trenches so that they could be reached without difficulty for alteration or repair. For this purpose a concrete pipe tunnel, 8 ft. 6 in. by 6 ft. 0 in., and 603 ft. long (Fig. 8), leading from the Boiler-House and crossing the Yard at right angles to the line of tracks, and thirteen concrete pipe trenches, 2 ft. in clear width, of varying depth, and of a total length of 12 325 ft., connecting with the tunnel and running parallel with and between every other track, have been constructed. Embedded in

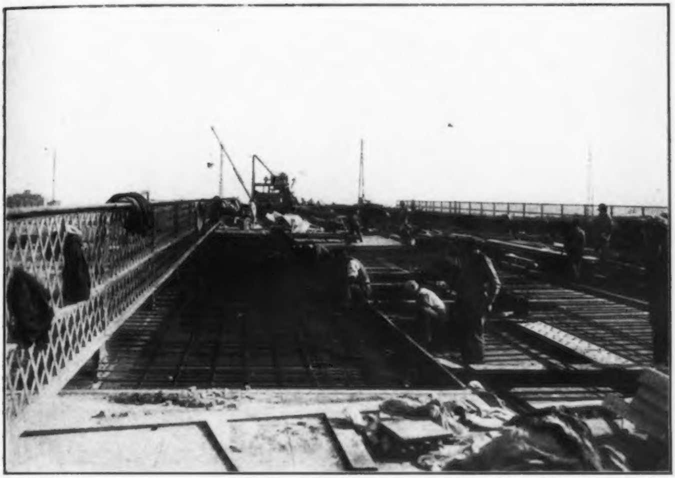


FIG. 1.—FLOOR REINFORCEMENT, BRIDGE APPROACH VIADUCT.

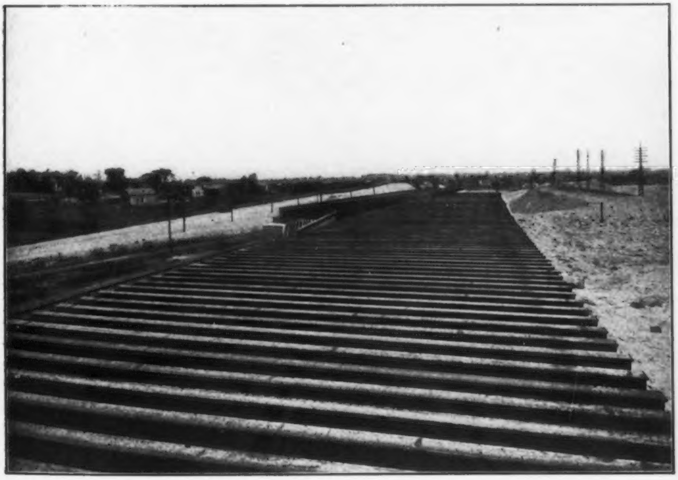


FIG. 2.—VIEW OF BRIDGE NO. 2 BEFORE PLACING CONCRETE FLOOR.

PLATE LIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1163.
BARKER ON
PENNSYLVANIA R. R. TUNNELS: THE SUNNYSIDE YARD.

FIG. 1.—RAILROAD BRIDGE FOR EIGHT TRACKS OVER LAUREL HILL AVE. AND THE LOOP TRACKS.

FIG. 2.—VIEW OF YARD BUILDINGS UNDER CONSTRUCTION.

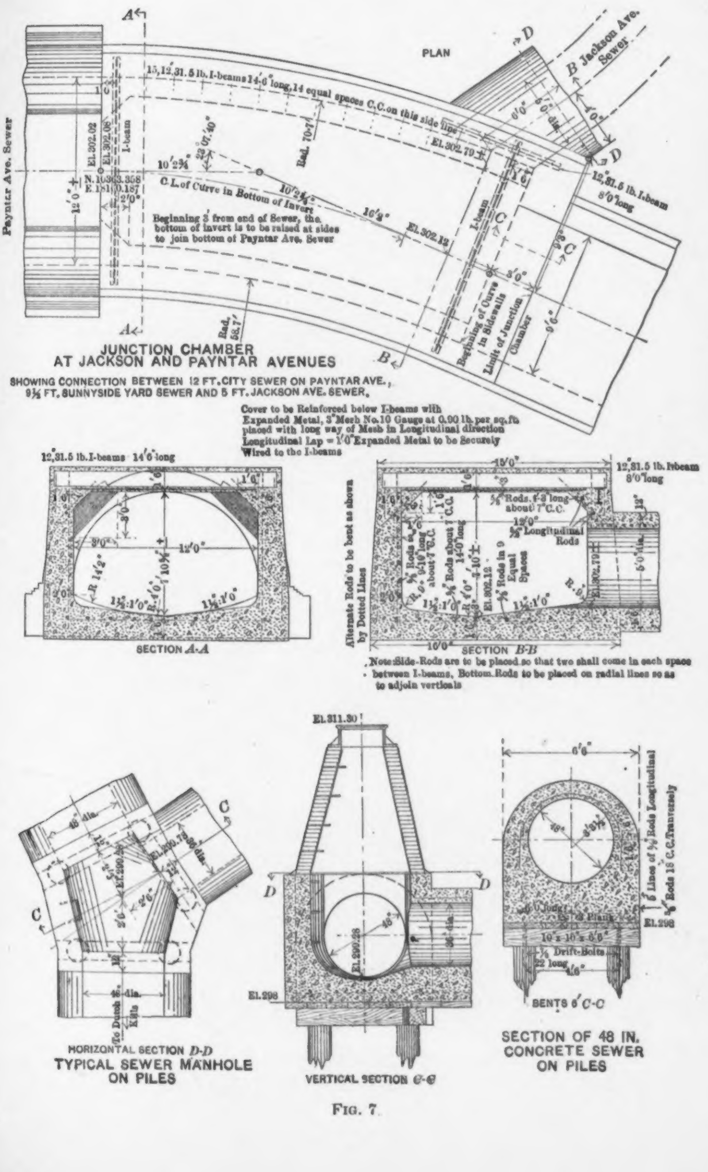

PLAN
Payntar Ave. Sewer
Jackson Ave. Sewer
15, 12" 31.5 lb. I-beams 14'-6" long, 14 equal spaces C.C. on this side line
C.L. of Curve in Bottom of Invert
Beginning 3' from end of Sewer, the bottom of invert is to be raised at sides to join bottom of Payntar Ave. Sewer
12" 31.5 lb. I-beam 8'0" long
Beginning of Curve in Sidewalls
Limit of Junction Chamber
JUNCTION CHAMBER
AT JACKSON AND PAYNTAR AVENUES
SHOWING CONNECTION BETWEEN 12 FT. CITY SEWER ON PAYNTAR AVE., 9½ FT. SUNNYSIDE YARD SEWER AND 5 FT. JACKSON AVE. SEWER.
Cover to be Reinforced below I-beams with Expanded Metal, 3" Mesh No. 10 Gauge at 0.90 lb. per sq. ft. placed with long way of Mesh in Longitudinal direction Longitudinal Lap = 1'0" Expanded Metal to be Securely Wired to the I-beams
12" 31.5 lb. I-beams 14'6" long
SECTION A-A
Alternate Rods to be bent as shown by Dotted Lines
SECTION B-B
Note: Side-Rods are to be placed so that two shall come in each space between I-beams. Bottom Rods to be placed on radial lines so as to adjoin verticals
HORIZONTAL SECTION D-D
TYPICAL SEWER MANHOLE ON PILES
VERTICAL SECTION C-C
BENTS 6' C-C
SECTION OF 48 IN. CONCRETE SEWER ON PILES

FIG. 7

both sides of these trenches there are two 2½-in. and one 2-in. lines of fiber conduit for carrying wires. Fig. 2, Plate LV, shows these pipe trenches before the 4-in. plank covering had been put in place.

The total quantity of cement used on all the work up to June 1st, 1910, was as follows:

Giant	125 108	bbl.
Atlas	8 245	"
Alsen (American)	8 047	"
Total	141 400	"

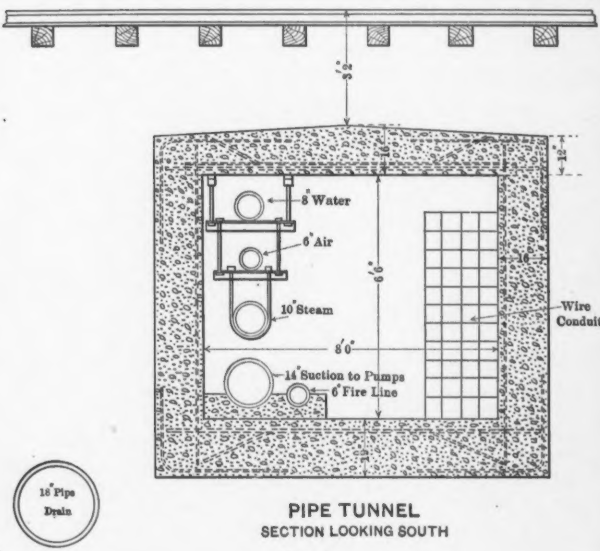


FIG. 8.

The entire Yard area will be enclosed by an iron picket fence, 7 ft. high, with 3-in. I-beam posts set in concrete bases.

An electrically-operated turn-table, 100 ft. in diameter, with concrete walls, has been built at the east end of the Yard.

The Sunnyside Yard, being a section of the East River Division of the Tunnel Extension, its construction was in charge of Alfred Noble, Past-President, Am. Soc. C. E., Chief Engineer from the beginning

FIG. 1.—VIEW OF 9 FT. 6 IN. BY 6 FT. 10 IN. SEWER ON PILES, BEFORE COVERING.

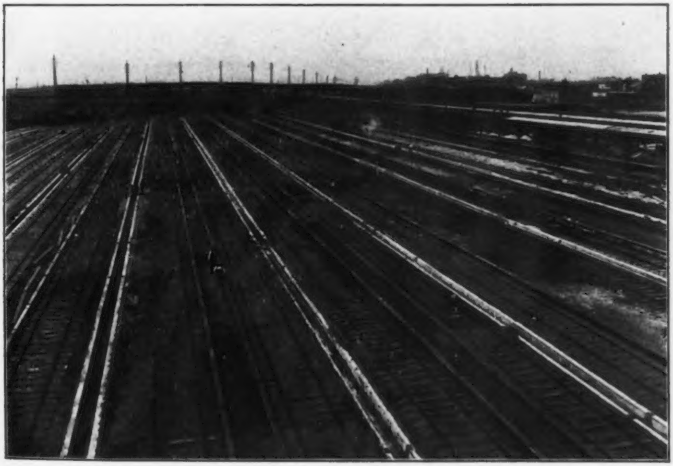


FIG. 2.—VIEW OF PIPE TRENCHES UNDER CONSTRUCTION.

of the work up to the time of his resignation, December 31st, 1909. Since that date George Gibbs, M. Am. Soc. C. E., Chief Engineer of Electric Traction and Station Construction, has had charge of the completion of this, as well as all other work in connection with the Yard.

F. M. Green, Assoc. M. Am. Soc. C. E., Designing Engineer in the office of the Chief Engineer, has furnished the information herein relative to the design of the bridges, and the loads and stresses assumed and used in their calculations.

AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1164

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. CERTAIN ENGINEERING STRUCTURES OF THE NEW YORK TERMINAL AREA.*

By George B. Francis and Joseph H. O'Brien,
Members, Am. Soc. C. E.

Introduction.

The location, general purpose, preparation of site, train schedules, trackage details, method of operation, and service work, have been described in other papers; this paper is confined to a description of the physical construction work of bridging over the approaches, bridging for the surrounding streets, foundations, substructures for various services, and the steel design for the Station Building.

The work herein described was placed under construction through the following primary contracts:

First.—A contract with the "American Bridge Company, of New York," dated June 1st, 1905, for the manufacture and delivery of the steel for street bridging, for the entire terminal, comprising about eight acres. The work under this contract was started in June, and the first deliveries were made in August, 1905. The major portion was delivered by January 31st, 1907, and all deliveries were completed

* Presented at the meeting of September 6th, 1911.

by April 30th, 1909. The work fabricated and delivered under this contract amounted to about 23 500 tons.

Second.—A contract with the "New York Contracting Company-Pennsylvania Terminal," dated June 21st, 1905, for the "Easterly Portion," embracing all excavation, masonry, and steel construction from the west line of Seventh Avenue, eastward to the normal tunnel sections in 32d and 33d Streets, covering about 290 ft. of line in 32d Street and about 500 ft. in 33d Street. The work was started on June 13th, 1906, and was practically completed in July, 1909. The amount of work done on the more important items was substantially as follows:

Excavation, earth	39 000 cu. yd.
Excavation, rock	133 794 cu. yd.
Concrete	28 930 cu. yd.
Water-proofing	17 500 sq. yd.
Back-filling, earth	58 850 cu. yd.
Duct work	47 676 duct ft.
Drainage	2 557 lin. ft.
Steel erected	8 944.8 tons.

Third.—A contract with the "New York Contracting Company-Pennsylvania Terminal," dated June 21st, 1905, for the construction of the viaducts west of Seventh Avenue, embracing all excavation, masonry, steel erection, and street-surfacing construction, for the viaducts for Eighth and Ninth Avenues, and 31st and 33d Streets. The work was started on October 19th, 1905, and was practically completed in January, 1910. The amount of work done on the more important items was substantially as follows:

Excavation, earth	2 300 cu. yd.
Excavation, rock	8 900 cu. yd.
Concrete	34 000 cu. yd.
Water-proofing	30 500 sq. yd.
Back-filling, earth	67 000 cu. yd.
Steel erected	14 400 tons.

Fourth.—A contract with the "New York Contracting Company-Pennsylvania Terminal," dated May 9th, 1906, for the substructures, embracing the excavation for and construction of all sub-

structures below track grade, such as foundations for the Passenger Station Building, pipe tunnels, baggage-trucking tunnels, electric ducts, drainage system, elevator pits, etc., etc. The work was started on June 1st, 1906, and was practically completed in January, 1910. The amount of work done on the more important items was substantially as follows:

Excavation, earth	8 300	cu. yd.
Excavation, rock	113 400	cu. yd.
Back-fill, earth	36 600	cu. yd.
Concrete	46 000	cu. yd.
Water-proofing	58 700	sq. yd.
Duct work	348 000	duct ft.
Drainage	33 700	lin. ft.

Fifth.—A contract with "Milliken Brothers, Incorporated," dated January 9th, 1906, for the manufacture and delivery of steel for the Passenger Station Building. The work was started immediately, and the first deliveries were made in May, 1907.

The contractors went into the hands of receivers in June, 1907, after delivering about 500 tons of material. By agreements with the receivers, dated September 6th and September 30th, 1907, this firm completed and delivered about 1 850 tons of additional material by November, 1907. The remaining steel for this building was furnished by other contractors.

Sixth.—A contract with "Milliken Brothers, Incorporated," dated January 9th, 1906, for the manufacture and delivery of steel for the Terminal Service Building. The work was started immediately, and the first deliveries were made in October, 1906. All deliveries were completed in April, 1907. The amount fabricated and delivered was about 2 437 tons.

Seventh.—A contract with the "American Bridge Company, of New York," dated July 17th, 1907, for the manufacture and delivery of steel for the Passenger Station Building, not furnished by Milliken Brothers or Receivers of Milliken Brothers. The work was started in September, 1907, and all deliveries were completed in March, 1909. The amount of work fabricated and delivered was about 24 662 tons.

Easterly Portion.

An important division of the terminal work was designated the "Easterly Portion." It embraced all the work of excavation, masonry, and bridging east of the west line of Seventh Avenue, and extending eastward under 32d and 33d Streets to the normal tunnel sections, covering an area of 1.88 acres, of which 0.51 acre is under private property and the remainder under public highways.

The franchise required that the tops of the finished structures should be 19 ft. below the surface of the streets and avenue. As this requirement was obviously made to provide space for a future rapid transit subway in Seventh Avenue, consideration was first given to the feasibility of effecting an arrangement with the city for the joint construction of the railroad's structure and a section of rapid transit subway in Seventh Avenue supported thereon.

Such an arrangement, however, could not be effected in any reasonable manner, owing to the impracticability at that time of determining future subway requirements, and therefore it was determined to restore the highways by back-filling over the railroad's structures. The portions of the latter under public thoroughfares were designed to support the load due to this heavy fill in addition to a uniform live load of 300 lb. per sq. ft., this total superimposed load aggregating about 3 500 lb. per sq. ft.

Owing to the great value of the private property affected, it was determined to design the structures beneath the private premises to sustain a superimposed load of 5 tons per sq. ft. The profile of the railroad line established the top of rail at about 49 ft. below the street level, and an under-clearance of 16 ft. 2 in. above the top of rail was also determined. Borings at the site disclosed the fact that rock underlaid the surface at an average depth of about 13 ft. A steel-roofed tunnel, with masonry abutment walls and intermediate steel bents, was adopted, and it was determined to set the steel roof girders parallel with the axis of Seventh Avenue in order to facilitate construction and provide properly for the maintenance of the avenue traffic.

Bents were introduced between tracks wherever practicable, but, owing to the track layout, long spans could not be wholly avoided. The spans vary from 20 ft. 6 in. to 81 ft. 2½ in. from center to center of bearings. The girders vary in depth from 3 to 9 ft., and are spaced

at 4-ft. centers where loads permit, but at 2-ft. centers where provision is made for loads from future buildings. To permit of simple details, and to avoid the use of excessively thick material, one-eighth of the deep girder webs was counted as flange section, and web splices were designed to resist moment. Cut granite templates are provided for the wall bearings of the smaller girders, and steel I-beam grillages for the wall bearings of the heavily loaded girders. These grillages are built up with separators, and provided with top and bottom countersunk riveted plates. The columns in intermediate bents are made up of two 15-in. channels, set about 15 in. from back to back, reinforced by 15-in. cover-plates, and double-latticed with $2\frac{1}{2}$ by $\frac{3}{8}$-in. bars, provided with riveted diaphragms at top and bottom, with riveted cap plates, field-connected plate, and angle knee-braces, and riveted plate and angle bases. The columns bear on cut granite templates capping concrete bases where loads permit, but the more heavily loaded columns bear on steel I-beam grillages, which in turn rest on granite masonry with concrete bases footed on the rock. Girders rest on the tops of columns. Curb angles are attached by riveted connections to the columns of all bents 4 ft. above top of rail for the protection of the fender walls.

The abutment walls are of gravity sections of 1:2:4 concrete, designed to carry the roof loads only, with an allowance of 30 tons per sq. ft. bearing value under the grillages. A granolithic top dressing is laid on top of these abutment walls under all grillage bearings. In situations where property was less valuable, and other conditions less restricting, the design of abutment walls capable of resisting hydrostatic pressure due to a head measured from the bottoms of the sewers might have been warranted. In this instance, however, it was determined to design the walls as above stated, trusting to a drainage scheme to relieve these walls of hydrostatic pressure.

The scheme consists merely of the application of well-known materials in a simple but unusual manner, namely, the space from standard section line to ledge, varying from 6 in. to 4 or 5 ft., is filled back of a suitable form to the full height of the abutment walls, with a porous concrete, 1 part cement, 4 parts sand, and 8 parts stone. This porous backing is faced with hollow, light-burned, porous, terra cotta, 12 by 12 by 4-in. partition blocks, laid with openings set vertically, and bonded for the continuity of the vertical hollow spaces. These

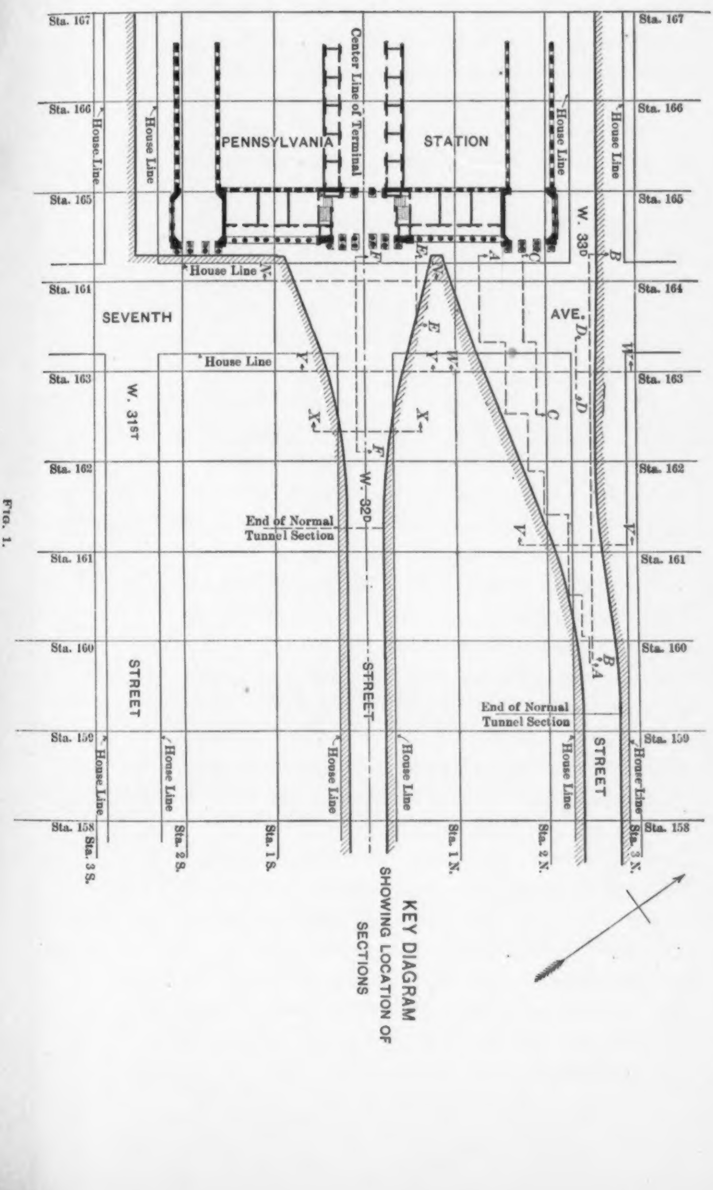

PENNSYLVANIA STATION
Center Line of Terminal
SEVENTH AVE.
W. 31ST STREET
W. 32D STREET
W. 33D STREET
House Line
End of Normal Tunnel Section
Sta. 167
Sta. 166
Sta. 165
Sta. 164
Sta. 163
Sta. 162
Sta. 161
Sta. 160
Sta. 159
Sta. 158
Sta. 3 S.
Sta. 2 S.
Sta. 1 S.
Sta. 1 N.
Sta. 2 N.
Sta. 3 N.
KEY DIAGRAM SHOWING LOCATION OF SECTIONS

FIG. 1.

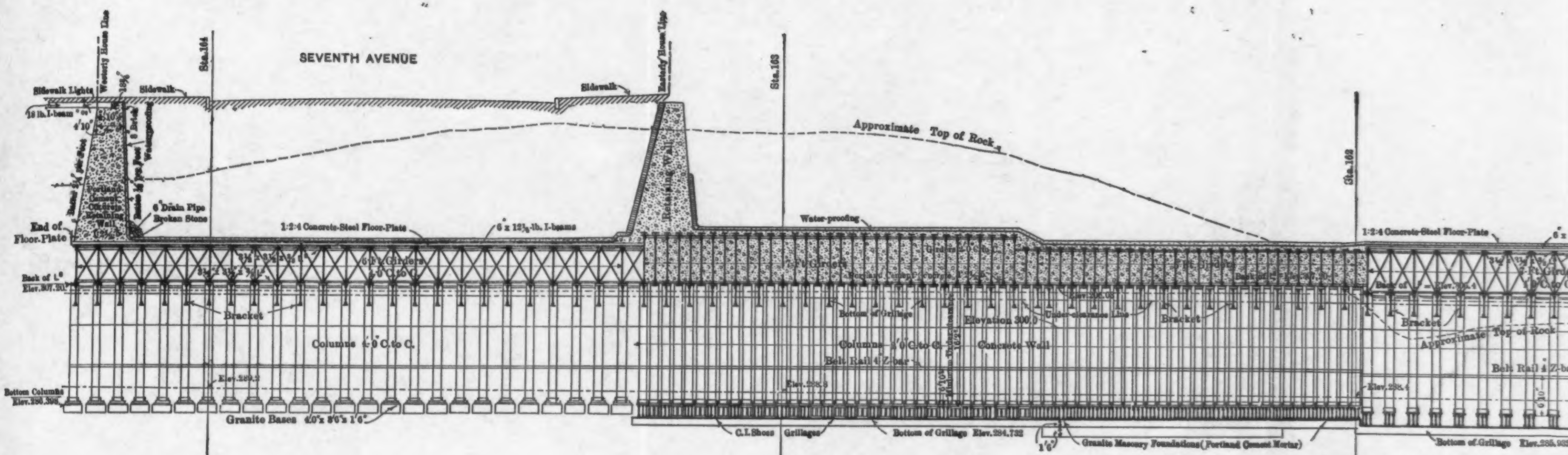
blocks are anchored to the concrete backing by cut nails, driven into the latter and clinched over the inner walls of the blocks or joints. The bed joints are buttered in such manner that the back half of the joint is left open as far as practicable; the build joints are made in a similar manner.

The tile drainage sheet is footed on a longitudinal tile drain, made by chipping out the end walls and partitions of the blocks. This longitudinal drain is connected with a gutter at the toe of the abutment wall, which, in turn, is connected to the under-drainage system. On the face of the tiling above described, the wall water-proofing is placed for the full height, with dry laps extended over the backing wall and weighted down. A section at a time, varying from 25 to 50 ft., was thus prepared, and the abutment walls were completed as soon as practicable after water-proofing.

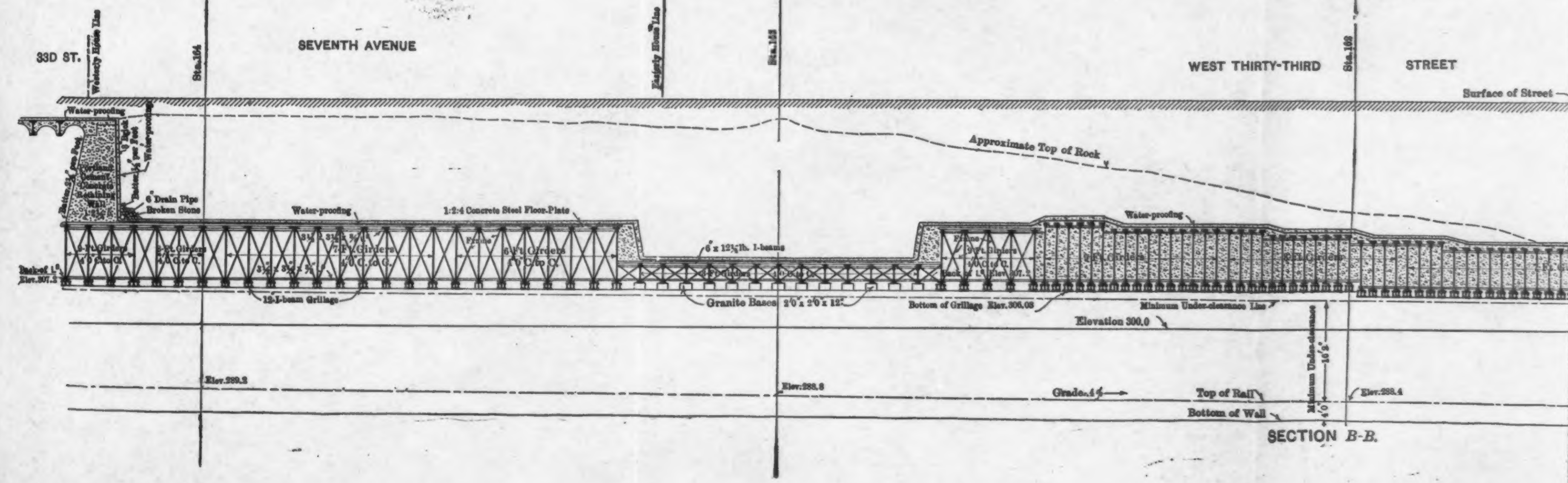
The roof cover, or so-called floor-plate, consists of plain I-beams, 4 and 6 in. deep, embedded in concrete and laid across the girders at intervals of 9 in. from center to center. The beams are not attached to the girders. The roof water-proofing is laid on top of the concrete-steel floor-plate, and a protecting cover of concrete is laid over the water-proofing; after this had been done the highways were back-filled.

The method of placing the concrete-steel floor-plate was as follows: First, forms were set between girders, then the plain I-beams were assembled, wire-brushed, spaced, and pinned up to grade; then mortar bearings were made for each beam over each girder, thus permitting, after the mortar had set, the removal of all wedges and spacers, and the cleaning of forms; after which the spaces beneath and between the beams were grouted, and the concrete was screeded to grade.

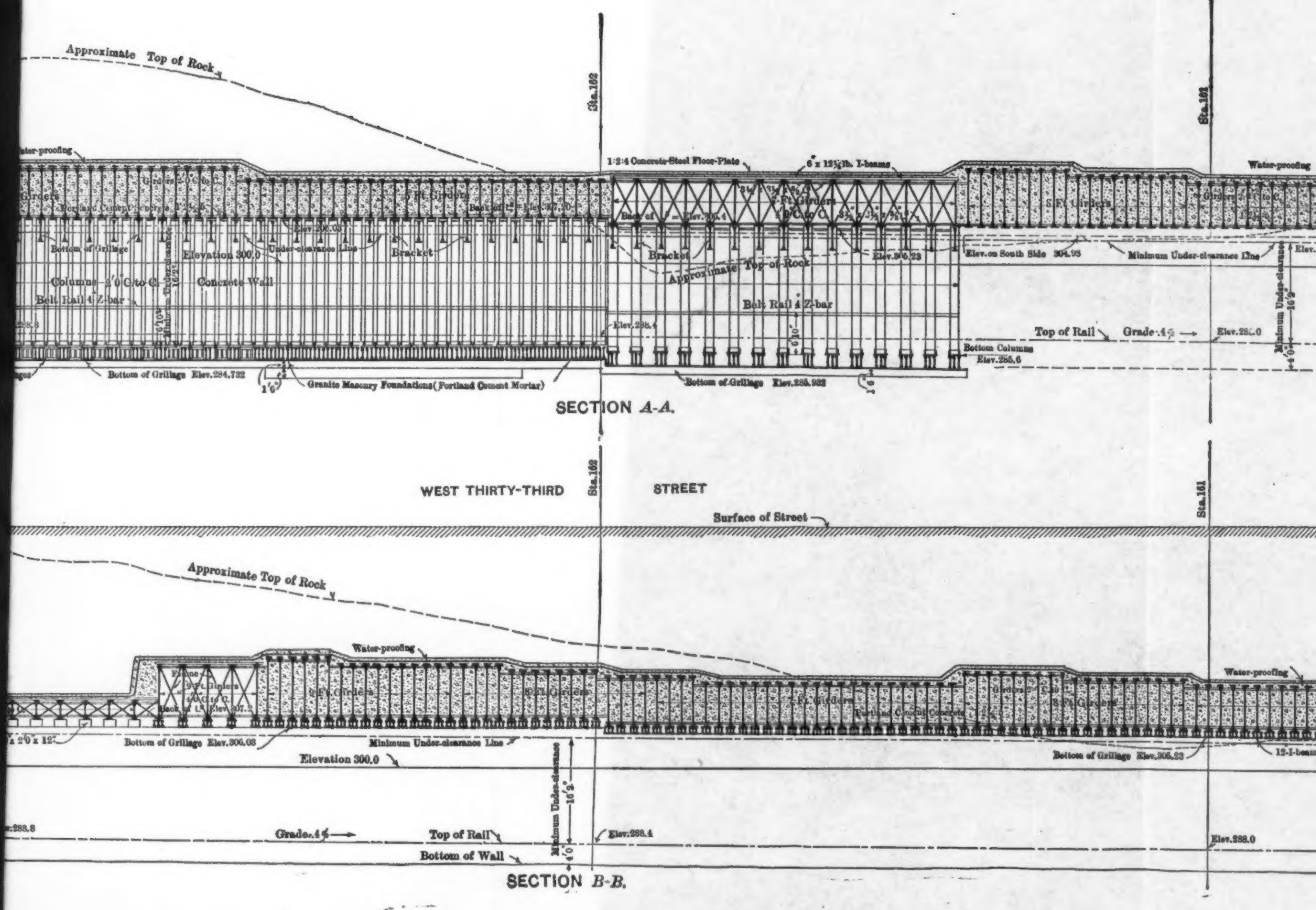
The protecting cover over the water-proofing was designed to be of plain concrete from 4 to 6 in. thick. As long as the back-filling was kept well back of the end of the completed work, and was stepped off in bench formation, the plain concrete cover served its purpose, but, in one case, when the back-filling was advanced in bank formation, close upon the completed construction work, the concrete cover broke, and the water-proofing was damaged, requiring the removal of much back-filling to effect proper repairs. After the occurrence just cited, the cover was reinforced by Clinton wire cloth, and no further trouble was experienced.



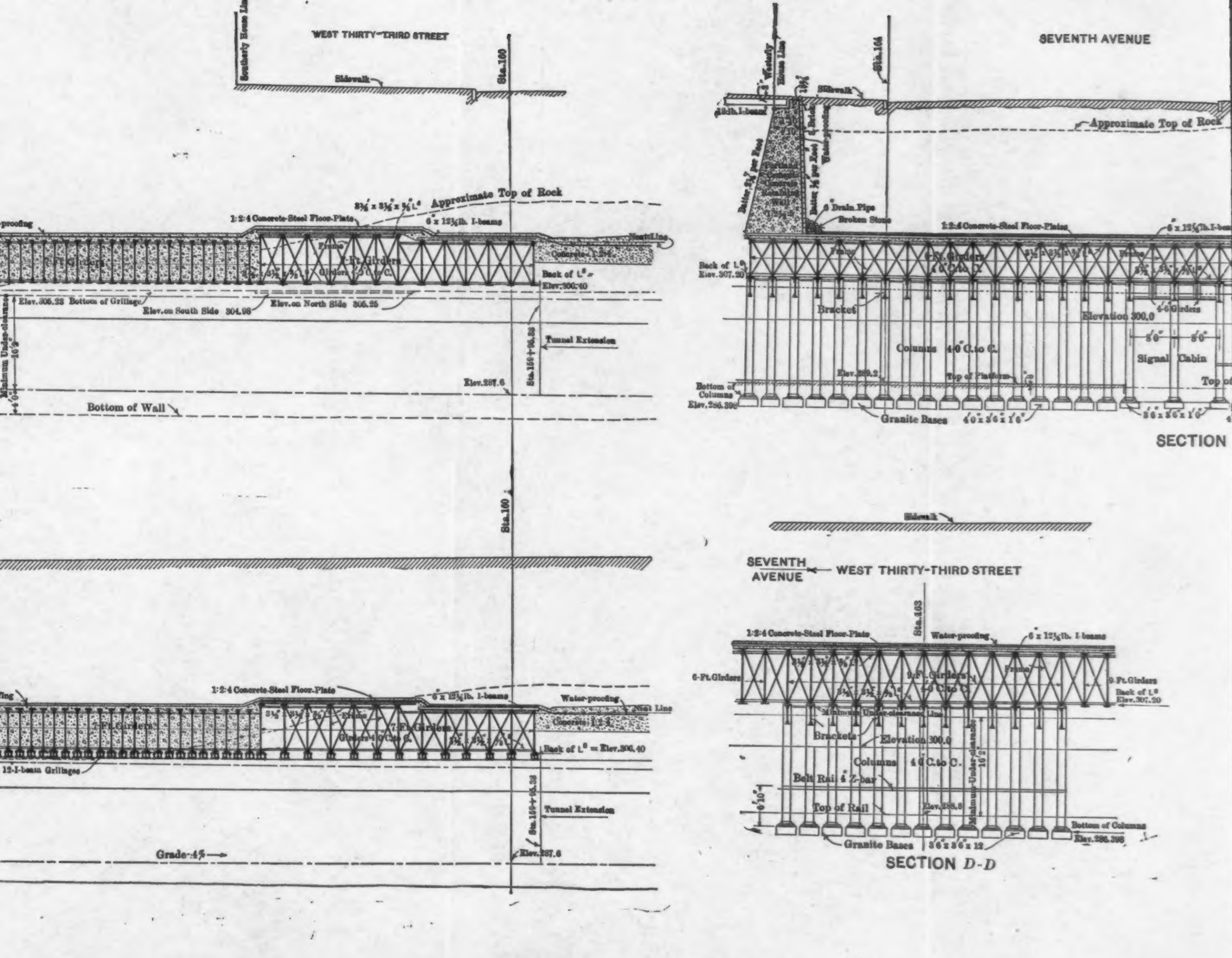
SECTION *A-A.*



SECTION *B-B.*

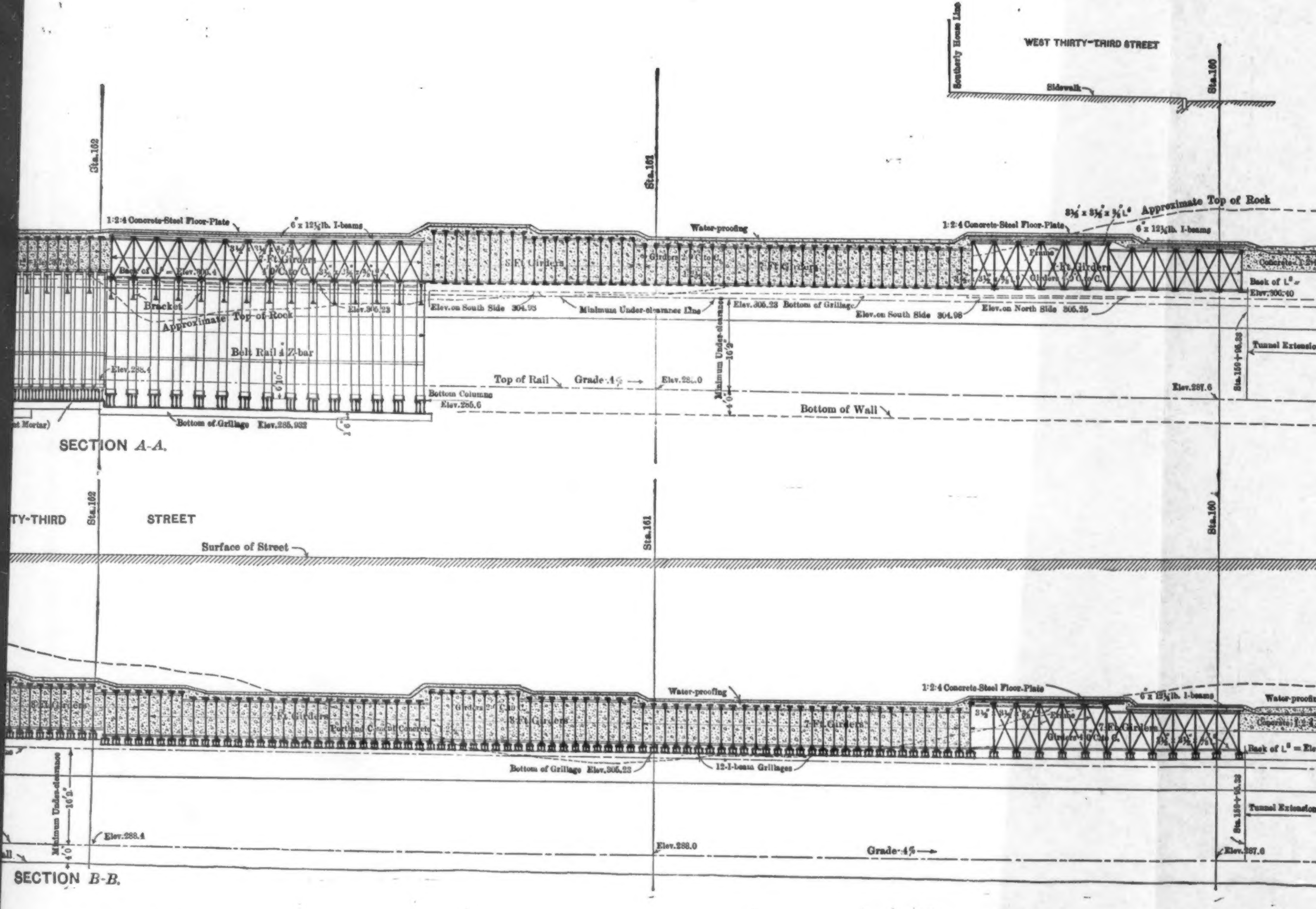


Approximate Top of Rock
Sta.162
Sta.161
1:2:4 Concrete-Steel Floor-Plate
Water-proofing
Bottom of Grillage
Elevation 300.0
Under-clearance Line
Bracket
Approximate Top of Rock
Columns 2'0" C. to C.
Concrete Wall
Belt Rail 4" Z-bar
Elev.on South Side 304.98
Minimum Under-clearance Line
Top of Rail
Elev.288.4
Bottom Columns
Elev.285.6
Bottom of Grillage Elev.284.732
Granite Masonry Foundations (Portland Cement Mortar)
Bottom of Grillage Elev.285.932
SECTION A-A.
WEST THIRTY-THIRD STREET
Surface of Street
Approximate Top of Rock
Water-proofing
Bottom of Grillage Elev.306.08
Minimum Under-clearance Line
Elevation 300.0
Bottom of Grillage Elev.305.23
Grade 4%
Top of Rail
Elev.288.4
Bottom of Wall
Elev.288.0
Minimum Under-clearance 16'2"
SECTION B-B.



WEST THIRTY-THIRD STREET
Southerly House Line
Sidewalk
Sta.160
Approximate Top of Rock
1:2:4 Concrete-Steel Floor-Plate
6" x 12¼lb. I-beams
Back of L⁸ = Elev.306.40
Elev.306.23 Bottom of Grillage
Elev.on South Side 304.98
Elev.on North Side 305.25
Tunnel Extension
Elev.287.6
Bottom of Wall
Water-proofing
12-I-beam Grillages
Grade-4%
SEVENTH AVENUE
Westerly House Line
Sta.164
Broken Stone
6" Drain Pipe
Back of L⁸ Elev.307.20
Bracket
Columns 4'0" C.to C.
Elevation 300.0
Signal Cabin
Elev.289.2
Top of Platform
Bottom of Columns Elev.286.398
Granite Bases
SECTION
Sidewalk
SEVENTH AVENUE
WEST THIRTY-THIRD STREET
Sta.163
6-Ft.Girders
9-Ft.Girders
Brackets
Belt Rail 4" Z-bar
Top of Rail
Elev.288.8
Bottom of Columns Elev.286.398
Granite Bases 3'6" x 3'6" x 12

SECTION *D-D*



WEST THIRTY-THIRD STREET
Southerly House Line
Sidewalk
Sta.162
Sta.161
Sta.160
Approximate Top of Rock
1:2:4 Concrete-Steel Floor-Plate
6" x 12¼lb. I-beams
Water-proofing
8 Ft. Girders
7 Ft. Girders
Bracket
Approximate Top of Rock
Belt Rail & Z-bar
Elev. on South Side 304.93
Minimum Under-clearance Line
Elev. 305.23 Bottom of Grillage
Elev. on South Side 304.98
Elev. on North Side 305.25
Minimum Under-clearance 16'2"
Top of Rail
Grade 4%
Bottom Columns Elev. 285.6
Bottom of Grillage Elev. 285.932
Bottom of Wall
Elev. 287.6
Tunnel Extension
SECTION A-A.
TY-THIRD
STREET
Surface of Street
Portland Cement Concrete
Bottom of Grillage Elev. 305.23
12-I-beam Grillages
Elev. 288.4
Elev. 288.0
Grade 4%
Elev. 287.6
SECTION B-B.

PLATE LVI.
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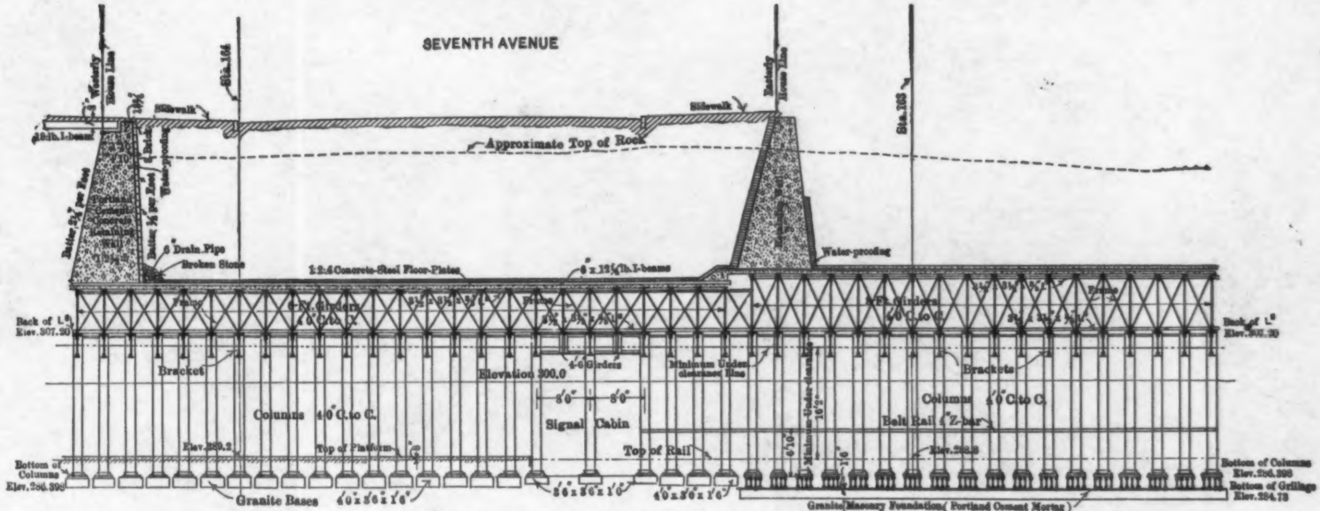
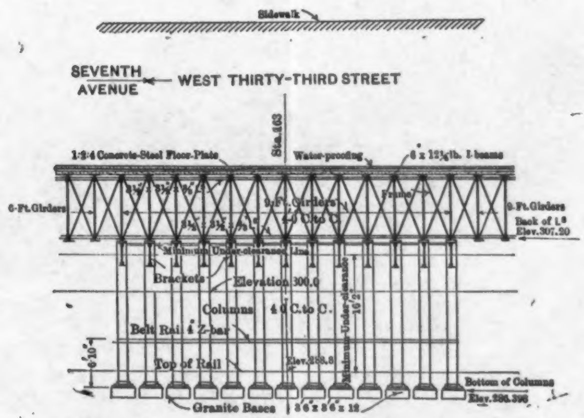


SECTION *C-C*



SECTION *D-D*

EASTERLY PORTION LONGITUDINAL SECTIONS OF THIRTY-THIRD STREET

The columns are encased in continuous concrete fender-walls, with battered faces, from the base of each column to 4 ft. above the top of rail. A reinforcing mesh is placed within 1 in. of the faces of these fender-walls in order to toughen the surface and reduce the tendency to check. Where the columns are at 2-ft. centers, a plumb curtain-wall is built above and monolithic with the battered fender-walls, and the columns are thereby filled and encased with concrete up to the knee-braces. Where the girders are at 2-ft. centers, they are solidly encased in concrete above the bottom flange cover-plates.

A superimposed wall is built along the west side of Seventh Avenue to retain the back-fill. Provision was made for similar walls elsewhere on the street lines, but company ownership of property permitted sloping the back-fill at these points, hence the walls were not built.

All abutment walls and column footings are founded below sub-grade on solid rock. All rock bottoms were carefully examined by the engineers and accepted by them before construction was permitted. As the excavation was through solid ledge, the engineers had principally to see that all soft, powder-burned, and loose rock was removed, and jagged, wedge-shaped surfaces cut down before accepting a foundation bottom.

Prior to the execution of the Easterly Portion contract, the masonry trunk sewers in Seventh Avenue, 32d and 33d Streets, within the limits of the Easterly Portion, were replaced, at the railroad company's expense, by cast-iron pipe sewers, 30 and 36 in. in diameter. These were maintained in position on falseworks during the conduct of the Easterly Portion contract. Substantial timber bents were left in place beneath them.

Excavation was started immediately after the contract was awarded, in June, 1905, and the procedure was briefly as follows:

Earth excavation was started east of Seventh Avenue, and for the first month was disposed of directly by wagons. An open cut was started west of the car tracks in Seventh Avenue at the end of the first month, and the west roadway was closed to traffic.

Derricks were erected to serve wagons east of Seventh Avenue in the second month. The excavation from the west cut was disposed of by 3-yd. dump-cars hauled to the North River dock by locomotives. The removal of service pipes from the west roadway of Seventh Avenue was started during the second month.

In the third month, a track connection was effected at grade across Seventh Avenue by the use of movable sections at the crossing of the street railway, and wagons were abandoned. A 300-ft. cableway was erected for the excavation of the west roadway of Seventh Avenue. A boiler was set up to serve the drills, and rock excavation was started east of Seventh Avenue.

During the fourth month, the construction of a temporary retaining wall was started along the north side of 33d Street, just north of the north abutment wall. This temporary retaining wall was suggested by the engineers and built by the contractors at their own expense to prevent serious damage to the buildings on the north side of 33d Street. These buildings are founded on the clay and hardpan above the ledge, and, owing to the construction of the temporary retaining wall in front of them, no appreciable settlement was noted.

During the fifth month, a cut-and-cover tunnel was commenced under Seventh Avenue in order to connect the two sections of the work.

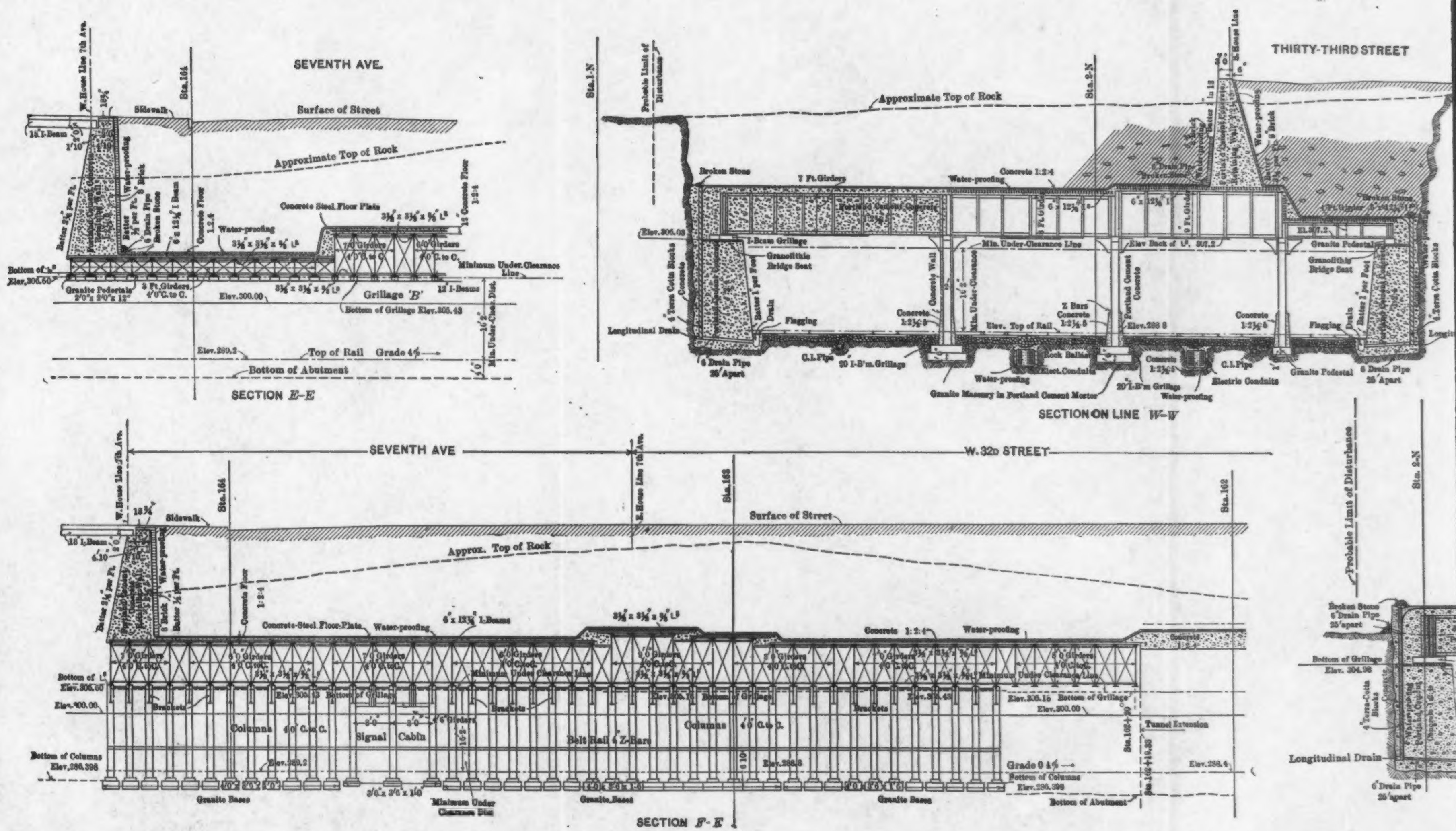
By the middle of the sixth month, the temporary retaining wall above referred to was finished, and the major portion of the north approach east of Seventh Avenue; the west roadway had also been excavated to an average depth of 28 ft. below street level, and a tunnel connection was effected, after which, all excavation was disposed of by way of the contractor's tracks below street level. The use of derricks and skips for serving the dump-cars was continued east of the west track in Seventh Avenue until the completion of the excavation. The cars were served chiefly by steam shovels in the west cut after the sixth month.

During the seventh month, a battery of boilers was erected south of the north cut east of Seventh Avenue, in order to supply steam for the derricks and drills.

The excavation of the 32d Street approach, east of Seventh Avenue, was started in the eighth month, and the highway was diverted to the company's property on the south.

After the completion of the temporary retaining wall, the north throat cut was widened to include 33d Street; and the highway was thereafter maintained on falseworks. Sub-grade was first reached in one year from the date of beginning excavation, at which time a considerable area in the west roadway of Seventh Avenue and a small area east of that avenue in the 33d Street approach reached bottom.

CROSS-SECTIONS ON 32D AND 33D STREETS



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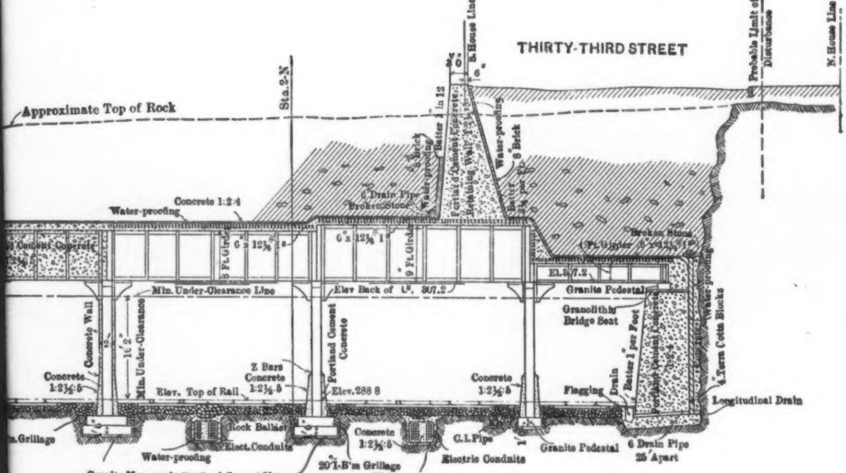
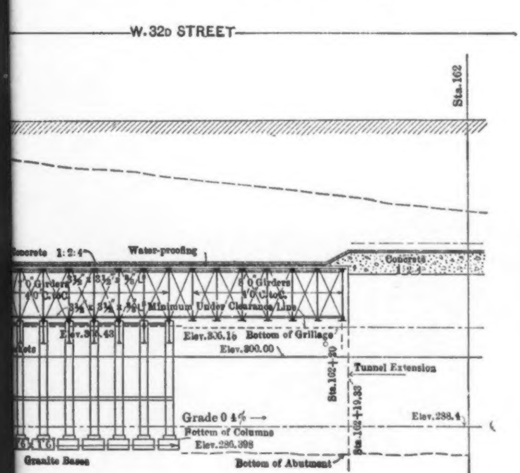
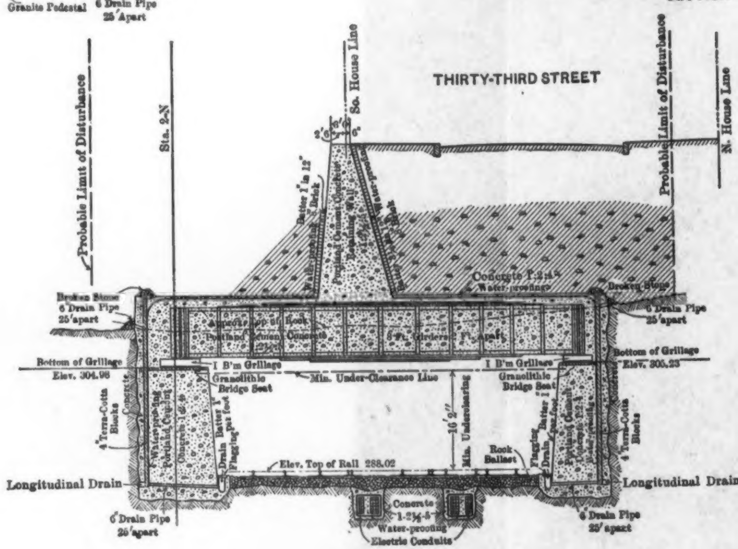
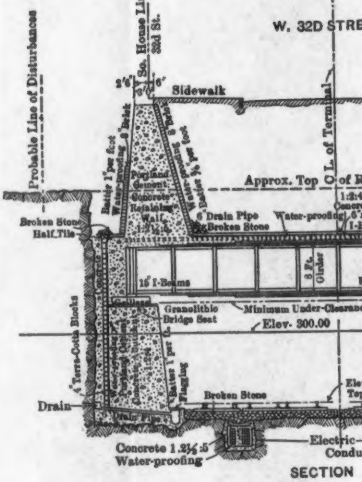


SECTION ON LINE *W–W*





SECTION ON LINE *V-V*



SECTION

PLATE LVII.
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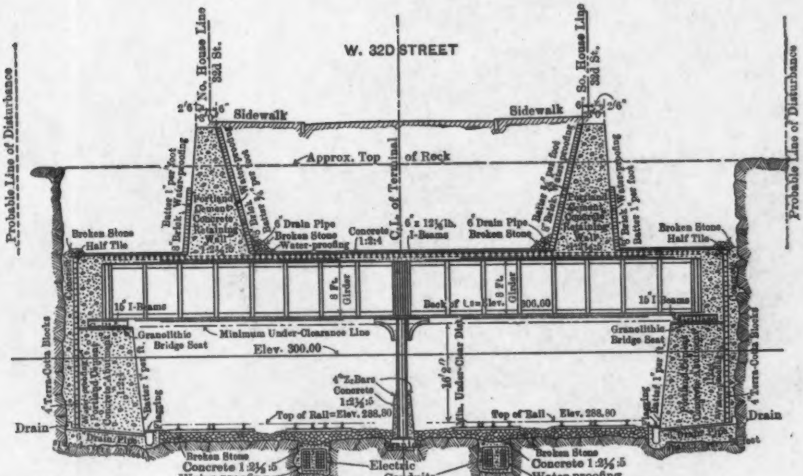
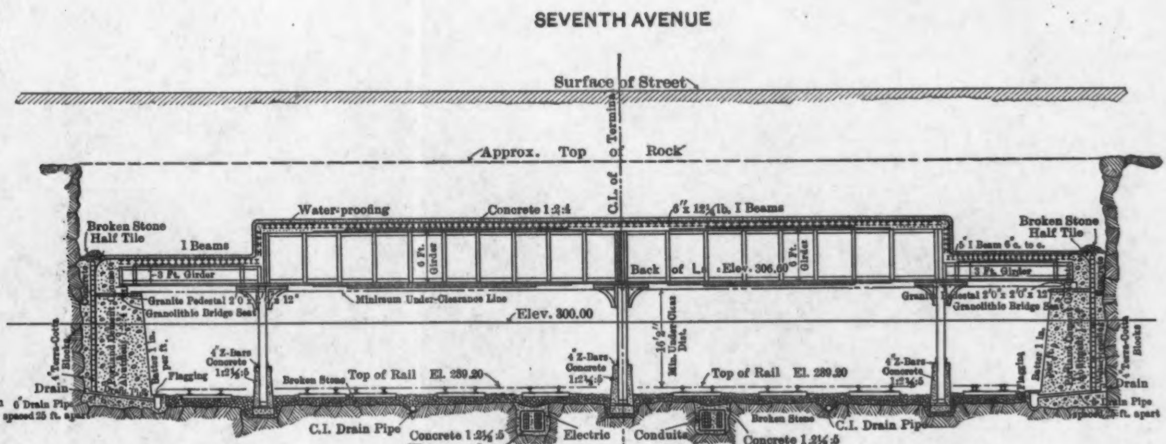
CTION X-X



SECTION Y-Y



SECTION Z-Z

Sub-grade was first reached in the 32d Street approach about three months later.

A concrete plant, with two 1-yd. Smith mixers, storage bins, and feed hoppers, was erected east of Seventh Avenue, between the two approaches, in April, 1907. This plant was set above the works, and the materials were delivered to it by a bucket conveyor, the concrete being discharged into 1-yd., metal dump-cars, by which it was distributed to the various works on industrial tracks placed on the forms and on a trestle built for the purpose. A section of backing wall for the south abutment, the 33d Street approach, and the foundations of the intermediate bents for this approach were started east of Seventh Avenue in May, 1907, and the first section of abutment wall was completed in that month.

The abutment walls for the south side of the 33d Street approach and the north side of the 32d Street approach west of the car tracks in Seventh Avenue, also the foundations for the center bent of the 32d Street approach west of the Seventh Avenue car tracks, were built during June, 1907. All abutments and foundations were partly completed during July, 1907, and the steel erection was started at the south end of the 32d Street approach west of the car tracks in Seventh Avenue. The steel erection for the 32d Street approach west of the car tracks in Seventh Avenue was completed on September 1st, 1907. The steel erection for the 33d Street approach east of Seventh Avenue was started on September 1st, 1907. The permanent structure was wholly completed west of the Seventh Avenue car tracks in December, 1908.

A temporary timber trestle was erected on the deck of the completed portion of the permanent structure, and the street-railway and other traffic in Seventh Avenue was diverted to this trestle on February 13th, 1908, after which the rock core which had been left beneath the street-railway tracks in the middle of Seventh Avenue was excavated. The excavation was entirely completed on September 30th, 1908. The abutment walls and foundations were completed on August 1st, 1908. The steel erection was completed about September 30th, 1908. All the floor-plate work, water-proofing, and protecting masonry were completed on October 6th, 1908. The back-filling for the restoration of the highways was started on the 33d Street approach east of Seventh Avenue on April 7th, 1908. A trestle was built over the permanent

bridging in Seventh Avenue, at the railroad company's expense, for the support of the street-railway tracks, the sewers, and the water and gas mains, in their permanent positions, and, after back-filling had been placed to the top of this trestle, the street railway was restored to its original location on January 5th, 1909, and four days later the east roadway of Seventh Avenue was paved and restored to traffic, thus permitting the completion of the west roadway, which was finished in May, 1909. The pavement on 33d Street east of Seventh Avenue was completed in January, 1909, and that on 32d Street east of Seventh Avenue in December, 1908. The company's property was fenced in, thus marking the virtual completion of this contract, about June 15th, 1909, four years from the date of beginning.

Owing to the heavy fill for the restoration of the streets and avenue it was determined to delay placing the final pavement until at least one year after the highways had been first restored to traffic.

Extracts from the specifications for the Easterly Portion are given in Appendix A. Extracts from the specifications for the manufacture of the steel for the Easterly Portion are given in Appendix B.

Viaducts.

The Eighth Avenue Viaduct.—This viaduct is 525 ft. long, 100 ft. wide, and extends entirely across the terminal between 31st and 33d Streets. Top of rail is about 39 ft. below street level at the south end of the viaduct and about 41 ft. below street level at the north end. After allowing for a minimum under-clearance of 16 ft. 2 in. and a minimum depth of 19 ft. from street level to top of structure, as required by the franchise, the permissible depth of structure over tracks was found to vary from 3 ft. 6 in. at the south end to 5 ft. 6 in. at the north end.

For the reasons stated under the heading "Easterly Portion," it was determined to restore the highway by back-filling over the viaduct roof, hence the latter was designed to support the weight of back-fill plus a uniform live load of 300 lb. per sq. ft., resulting in a total load of about 2 700 lb. per sq. ft.

Owing to the shallow working depths, the bents were located in all platforms and between tracks wherever possible. The resulting spans vary from 20 ft. 5 in. to 43 ft. 9 in. from center to center of bearings.

A riveted, face-connected, plate-girder structure, with riveted,

FIG. 1.—STEEL ROOFING, EASTERLY PORTION.

FIG. 2.—STEEL ROOFING AT THROAT, EASTERLY PORTION.

I-shaped columns, was adopted. The floor-plate is of 4-in. I-beams laid transversely, spaced from 6 to 8 in. on centers, spanning at least three girders, and breaking joints every sixth beam; it is similar in type to that described under the heading "Easterly Portion."

Superimposed retaining walls extend from the floor-plate to the street level on both faces of the viaduct; the basin thus formed is water-proofed, covered with masonry, and contains the back-filling.

The columns are uniformly spaced 10 ft. from center to center transversely of the viaduct; each is built up of one web-plate, 16 in. wide, four 8 by 6-in. L's, and from two to six cover-plates, 18 in. wide, having open holes at the top for girder connections, and riveted plate and fitted stiffener angle bases. The columns bear on cut granite cap-stones underpinned to solid rock, except as hereinafter noted, by concrete piers. Each column base is secured to the granite cap-stones by two 1¼-in. fox-bolts, 12 in. long.

Face-connected girders, varying in depth from 5 ft. to 7 ft. 2½ in., each built up of one web-plate, with four side-plates where required, and four 6 by 6-in. L's, and provided with open holes through riveted fillers for web connections with longitudinal girders, are framed between the columns transversely, thus completing the bents.

The longitudinal girders vary in depth from 2 ft. 4½ in. to 4 ft. 4½ in., and are 3 ft. 4 in. from center to center in the outer bays under the retaining walls, and 5 ft. from center to center between the outer bays. They are framed between the columns and transverse girders of the bents above described. Each longitudinal girder is built up of one web-plate, with four side-plates where required, four 6 by 6-in. or four 8 by 6-in. flange L's, and from two to six cover-plates.

The site of the viaduct was excavated to sub-grade, a timber trestle was erected to maintain the highway for traffic, and the north and south abutments were built under another contract.

Some interesting incidents of the construction of this viaduct are the following: Top of rock was found below track level over the greater portion of the south half of the viaduct, gradually rising to the surface of the avenue in the north half. Pockets of disintegrated feldspar, having the consistency of thoroughly compacted ashes, and saponifying in water, were encountered in several instances immediately beneath the viaduct foundations of the six southerly bents. Wash-borings at eighteen column locations showed the depth to solid

rock in these pockets to vary from 5 ft. to more than 30 ft. below sub-grade. After borings had been made, excavation was carried deep enough in all soft material to disclose the character and extent of the pockets, and further explorations were made, where required, with rock drills. In several instances the pockets were found to extend over the entire area of the column foundation, the depth to firm rock being more than 25 ft. below sub-grade. In such cases spread footings were built, based on conservative bearing values determined according to the conditions encountered in each case. In other instances the pockets tapered so that their area at moderate depths was found to be only a small percentage of the area of the piers. In these cases excavation was made until firm rock was encountered at depths of 6 to 16 ft. below sub-grade. In many other cases the rock bottom was badly seamed with mica schist and disintegrated rock, and in such instances spread footings were provided, based on the usual bearing values for hardpan.

The timber trestle occupied the middle of the viaduct site for a width of about 40 ft., hence almost half of the steel had to be placed through this trestle, and the latter had to be constantly readjusted, first during the building of foundations, then during the placing of steel, and afterward during the restoration of the service mains, etc.

Owing to the type of the permanent structure, it was hoped that the steelwork could be erected by working simultaneously in both directions from the center bent of the viaduct, but it happened that the south half was ready for the steelwork first, and therefore the erection was started at that end and continued steadily northward. The easterly bays were set in advance, and the remaining bays were filled in just back of them until the center bent was reached. The structure was constantly measured and plumbed, and riveted, but, when all the steel had been placed south of the center bent, check measurements were made and complete data obtained as to the position of the structure. It was found to be plumb and varying from $\frac{1}{4}$ to $\frac{7}{16}$ in. south of its true position at the center. Fillers were accordingly inserted as required on the north face of the center bent, and the erection proceeded, closing on the north abutment within $\frac{1}{4}$ in. of true position. The steel was erected in temperatures varying from about 20 to 90° Fahr., and the only provision against creep was the customary shortening of the girders from $\frac{1}{16}$ to $\frac{1}{8}$ in.

PLATE LIX.
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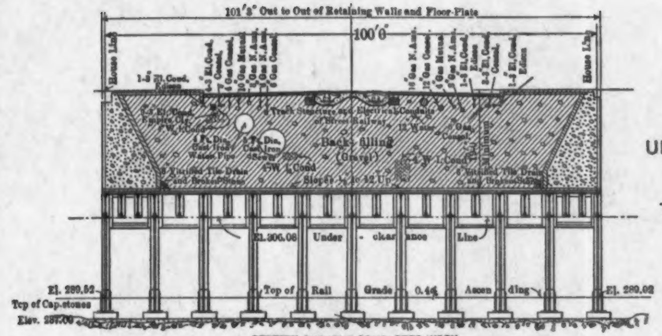
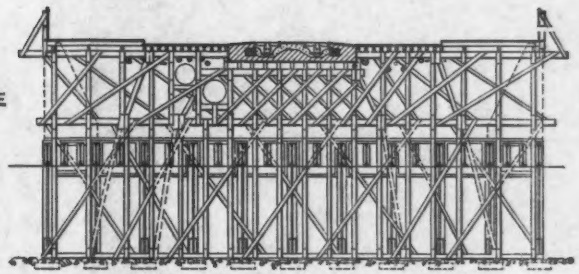
STEEL VIADUCT UNDER EIGHTH AVENUE

PLAN AND SECTIONS SHOWING RELATION OF TEMPORARY TO PERMANENT STRUCTURE

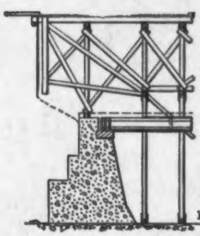


SECTION SHOWING COMPLETED WORK

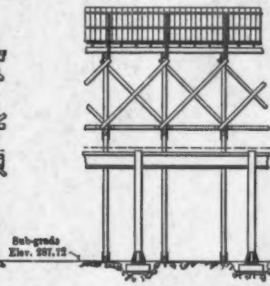


SECTION SHOWING FALSEWORK AND STEELWORK IN POSITION.

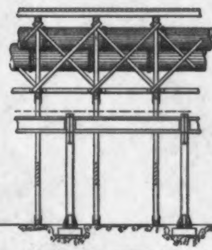
Note:- Timber Members that Interfere with Erected Position of Steel Girders are shown Dotted.



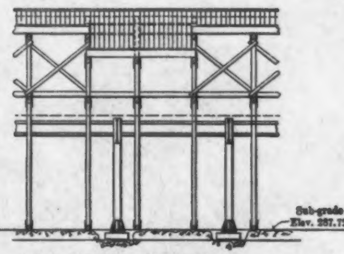
ELEVATION AT SOUTH END.



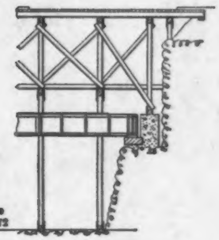
TYPICAL ELEVATION.



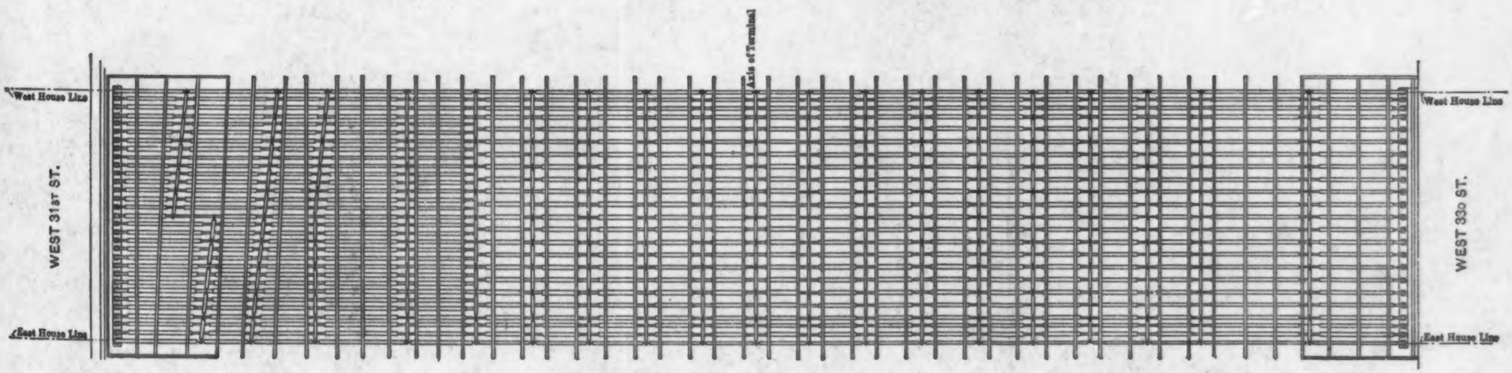
LONGITUDINAL SECTION WEST OF SEWER AND WATER PIPES.



LONGITUDINAL SECTION AT STREET RY. MANHOLE JUST EAST OF CTR. LINE.



ELEVATION AT NORTH END.



PLAN SHOWING FALSEWORK AND STEELWORK IN POSITION.

The back-filling, for the restoration of the highway, was advanced from south to north, in bench formation, as rapidly as the masonry cover was completed over the water-proofing. About at the center of the viaduct the back-filling was advanced too close upon the green masonry, and a settling down and bulging of the 8-in. backing wall was noted, accompanied by vertical cracks, due apparently to the slipping of the back-filling placed against the wall. To overcome the difficulty, the thickness of the backing was changed from 8 to 4 in., and a substantial footing was provided. No recurrence of the trouble was experienced after the section of the brick backing was modified. Portions of the timber trestle were left in place for the support of the street-railway tracks and the service mains. The street railway was jacked up, lined, and wedged to grade on this trestle support prior to paving. The highway was restored at first by granite block pavement in sand, and this temporary pavement was maintained in serviceable condition during the settlement of the back-fill. Permanent asphalt pavement will be provided eventually.

The sidewalks are of granolithic, top-dressed concrete on a cinder base, with cut stone curbs.

The excavation for the foundations was started in November, 1905, and completed in June, 1907. The foundation masonry was started in December, 1905, and completed in July, 1907. The steel erection was started in September, 1906, and completed in August, 1907. The superstructure masonry was started in May and completed in November, 1907. The back-filling for the restoration of the highway was started in July and completed in December, 1907. The temporary pavement was completed and the highway entirely restored to traffic in March, 1908, 2½ years after beginning work.

The 31st and 33d Street Viaducts.—These structures support the highways along the north and south margins of the terminal site, between Seventh and Eighth Avenues, between Eighth and Ninth Avenues, and along 31st Street for a distance of 200 ft. west of Ninth Avenue.

The franchise permitted the tops of these structures to be placed 2 ft. 6 in. below the street surface, except south of the south curb line of 31st Street and north of the north curb line of 33d Street, where it required a minimum depth of 5 ft.

The 31st Street Viaduct, between Seventh and Eighth Avenues, is 800 ft. long, 81 ft. wide for a distance of 160 ft. in front of the

Service Building, and 58 ft. wide elsewhere. It is supported on the north by the Station Building steelwork and on the south by a retaining wall, except in front of the Service Building, where it is supported by the steelwork of the latter. This viaduct has two main decks; the upper deck, in front of the Service Building, supports the highway and both sidewalks; elsewhere the upper deck supports a portion of the highway and the north sidewalk. Beneath the roadway deck there is a baggage passageway connecting the Seventh and Eighth Avenue ends of the Station Building. This baggage passageway deck also includes a carriage return driveway, just south of the general waiting-room, and a portion of the main concourse floor for the Station Building. It also includes a floor immediately in front of the Service Building for the support of apparatus.

Under a portion of the baggage passageway floor a pipe gallery has been constructed for service lines from the Service Building to the Station Building.

A column line was established just south of the north house line of 31st Street, and there are intermediate column supports for the viaduct opposite the columns of the south wall of the Station Building, and spaced at varying intervals from 11 ft. 8 in. to 30 ft. $6\frac{1}{2}$ in. from center to center. Columns were also located north of the Service Building for the support of the southerly margin of the highway and the baggage passageway.

The principal columns are made up of one $16\frac{1}{2}$ by $\frac{7}{16}$-in. web-plate, four 6 by $3\frac{1}{2}$ by $\frac{3}{4}$-in. angles, and two 15-in. 33-lb. channels, reinforced below the baggage passageway floor level, by two 12 by $\frac{3}{8}$-in. cover-plates, provided with open holes for the connection of the girders and beams of the baggage passageway floor and for girder connections at the top, and provided with riveted plate and stiffener angle bases. Riveted plate and angle brackets are provided at all connections between transverse girders and columns.

All but three of the columns bear on cut granite cap-stones underpinned to solid rock by concrete piers. Three of the columns rest on steel I-beam grillages underpinned to solid rock by concrete piers. The latter three column foundations are located between the conduit lines, where the available space did not permit of the economical use of stone templates. The foundation concrete is composed of 1 part Portland cement, $2\frac{1}{2}$ parts sand, and 5 parts broken stone.

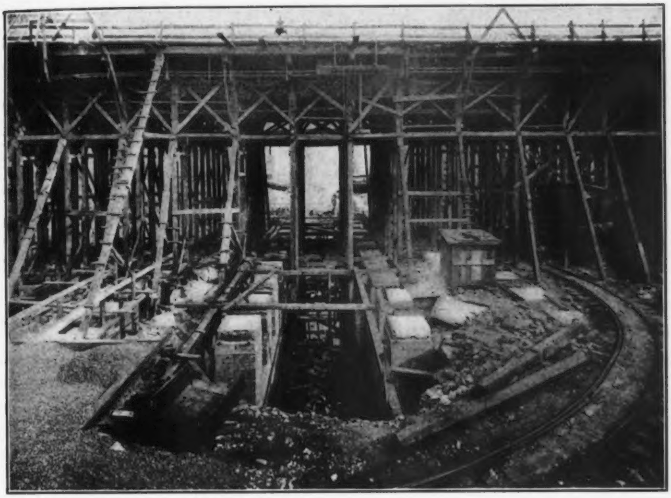


FIG. 1.—TEMPORARY BRIDGE, PERMANENT FOUNDATIONS, AND TRUCKING SUBWAY, EIGHTH AVENUE.

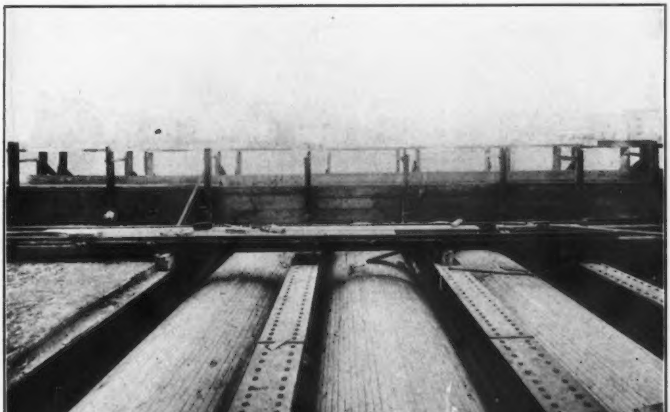


FIG. 2.—THIRTY-FIRST STREET BRIDGE FLOOR.

The deck immediately beneath the roadway is of plate-girder construction, the sidewalks being supported on I-beam framing. The sidewalk beams and roadway girders are approximately at 5-ft. centers, and set transversely of the viaduct. The roadway girders are face-connected on the north to longitudinal girders which frame between the viaduct columns, and are similarly connected on the south in front of the Service Building, but elsewhere on the south they are supported on the retaining wall bridge seat. These roadway deck girders are made up of one 24-in. web-plate, four 6 by 6-in. angles, and two 14-in. cover-plates. Between the roadway girders three-center spandrel arches were turned, with haunches bearing on the bottom flanges of the girders. These arches are of 1:2:4 Portland cement concrete, and are 12 in. thick at the crown, with tops leveled off 3 in. above the tops of the girders. This top surface is water-proofed with six-ply pitch and felt, connected to the water-proofing of the retaining wall, and turned up elsewhere back of the curbs. A protecting cover of 1:2½:5 Portland cement concrete, 4 in. thick, is placed over the water-proofing. The back-filling was placed over this cover, and the roadway was temporarily paved with granite blocks in sand. A temporary timber curb and bulkhead was constructed just south of the north curb line to retain the fill and pavement pending the setting of special curb and sidewalk lights in front of the Station Building. This temporary curb was subsequently used as the sill of the temporary fence enclosing the station site.

The baggage passageway floor is of steel-beam, plate-girder, and lattice-girder construction. The floor-beams vary from 15-in., 45-lb. I's to 24-in., 80-lb. I's; they are spaced about 5 ft. from center to center, and are set longitudinally, resting on the top chords of the transverse lattice girders of the pipe gallery; they are face-connected to the transverse plate girders elsewhere, with the tops of the beams set 1 in. below the girders.

The pipe gallery floor-beams vary from 10-in., 25-lb. I's to 12-in., 31½-lb. I's; they are spaced about 5 ft. from center to center, and are set longitudinally and face-connected to the transverse girders with the bottom of the beams 1 in. above the bottom flanges of the girders. Between and over the floor-beams of the pipe gallery and baggage passageway there are reinforced concrete floors, the slabs varying in thickness from 4 to 6 in., with beveled haunches footed on beam

flanges. These floors are of 1:2:4 Portland cement concrete (using ¾-in. stone), reinforced by Clinton wire cloth. The bottoms of the slabs are 1 in. below the tops of the beams. These reinforced concrete floors have a granolithic top dressing. The north side of the baggage passageway and pipe gallery and the southerly margin in front of the Service Building are enclosed by brick walls supported on the viaduct steelwork. A granolithic sidewalk, 2 ft. 6 in. wide, with Wainwright, steel-bow, concrete curb, 7 in. high, is laid on the baggage passageway floor against the north wall, and there is a quarter-round granolithic fender curb of 12-in. radius on the south side of the baggage passageway floor. The general excavation to sub-grade, the construction of the retaining wall, the Service Building, and the Station Building were done under other contracts.

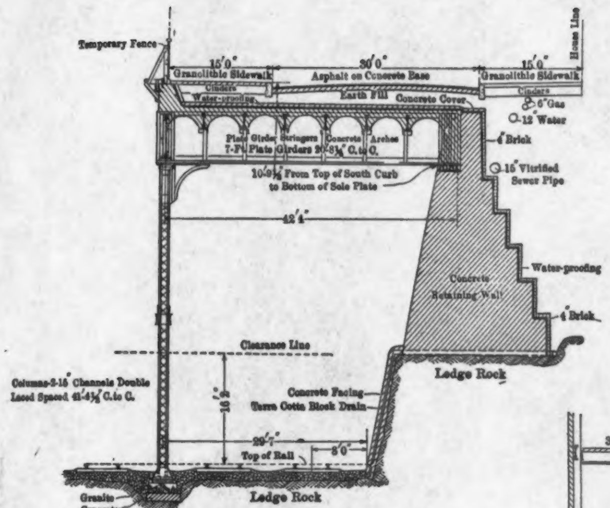
The excavation for the forty-three column foundations of this viaduct was started in June and completed in November, 1906. The foundations were started in April and completed in December, 1906. The steel erection was started in November, 1906, and completed in March, 1907. The superstructure masonry was started in March and completed in July, 1907. The temporary pavement was completed and the highway restored to traffic in November, 1907.

The 33d Street Viaduct, between Seventh and Eighth Avenues, is 800 ft. long, 78 ft. wide for a distance of 297 ft. opposite the general waiting-room, and 57 ft. wide elsewhere.

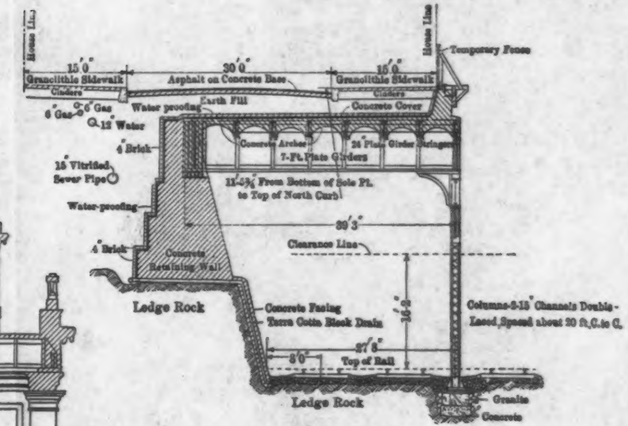
It is similar in type to the 31st Street Viaduct between Seventh and Eighth Avenues, hereinbefore described, but the lower deck in this case is a part of the exit concourse, and is arranged for future connections to rapid transit subways in Seventh and Eighth Avenues and 34th Street. The governing floor grades and the under-clearance left a permissible depth of only about 2 ft. for the lower deck. It was determined, therefore, to frame this lower deck transversely between the intermediate column line and the north retaining wall, and, opposite the general waiting-room, to the north column line. The floor-beams for the shorter spans vary from 15-in., 42-lb. I's to 18-in., 60-lb. I's. The long-span floor-beams are built up of 18-in. web-plates and four 6 by 4-in. L's, and 24-in. web-plates with four 6 by 6-in. L's. The floor-beams are spaced from 3 ft. 6 in. to 5 ft. from center to center, are face-connected to the longitudinal girders and columns on the column lines, and set into pockets in the ledge beneath the north retaining wall

PLATE LXI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1164.
FRANCIS AND O'BRIEN ON
PENNSYLVANIA R. R. TUNNELS: TERMINAL STRUCTURES.

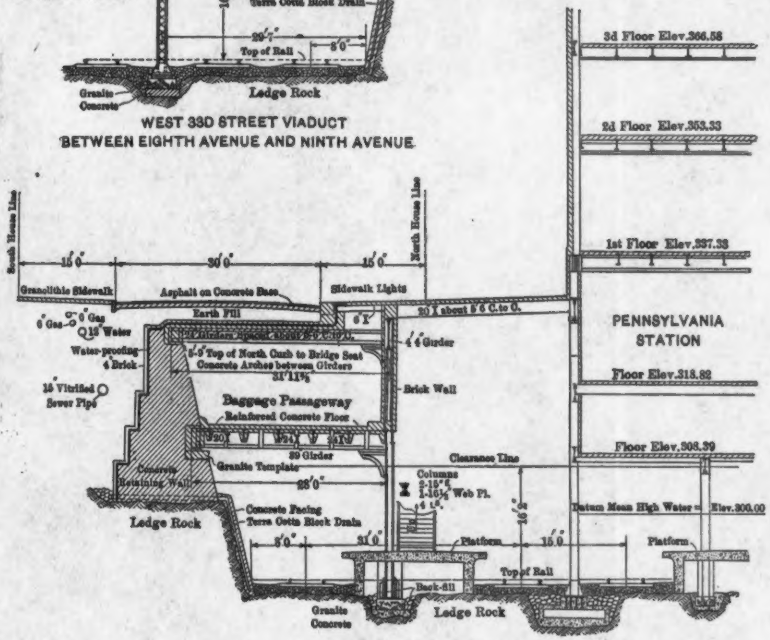
TYPICAL SECTIONS OF VIADUCTS ON WEST 31ST AND WEST 33D STREET



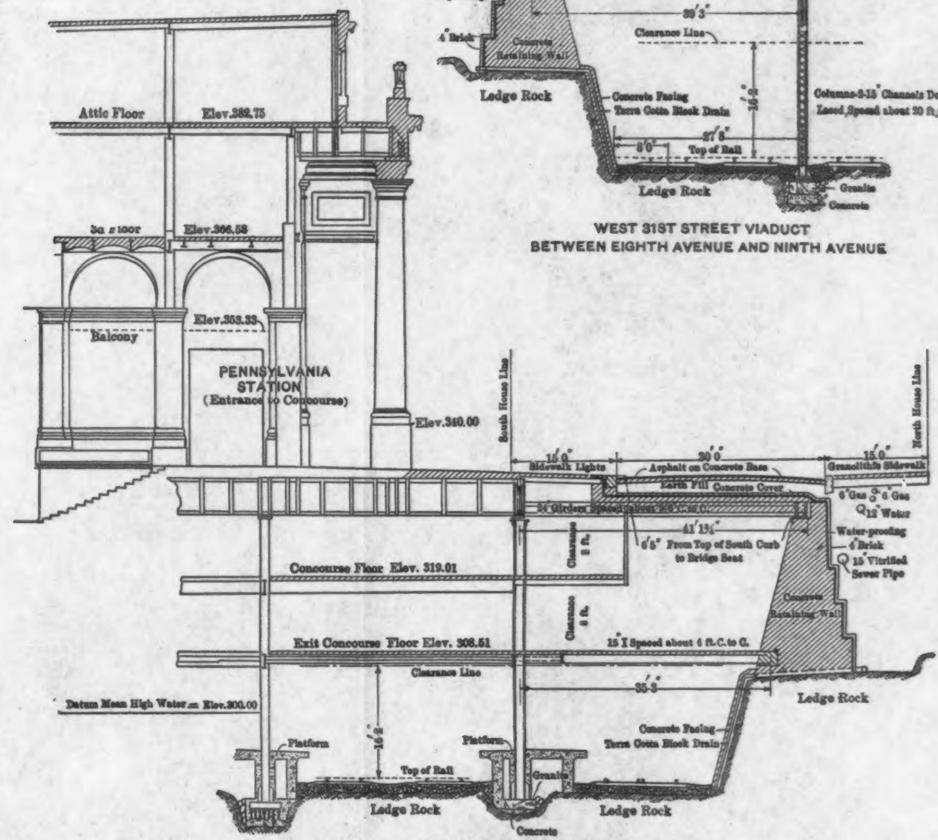
WEST 33D STREET VIADUCT
BETWEEN EIGHTH AVENUE AND NINTH AVENUE



WEST 31ST STREET VIADUCT
BETWEEN EIGHTH AVENUE AND NINTH AVENUE



WEST 31ST STREET VIADUCT
BETWEEN SEVENTH AVENUE AND EIGHTH AVENUE



WEST 33D STREET VIADUCT
BETWEEN SEVENTH AVENUE AND EIGHTH AVENUE

for a length of 247 ft. at the west end and on the pilasters forming part of a concrete facing placed over the ledge beneath the retaining wall for a length of 258 ft. at the east end.

A gallery, 15 ft. wide and 457 ft. long, supported on the viaduct columns on the south and suspended from the roadway deck girders on its northerly margin, forms a part of the entrance concourse, and is connected by stairway to the south sidewalk of 33d Street, and by a northerly extension to the 34th Street temporary entrance and exit.

The excavation to sub-grade, the construction of the retaining wall, the Station Building, and the temporary entrance and exit to 34th Street, also the architectural finish of the concourse deck of this viaduct were executed under other contracts.

The excavation for the fifty-six column foundations of this viaduct was started in October, 1906, and completed in September, 1907. The foundations were started in November, 1906, and completed in September, 1907. The steel erection was started in July and completed in December, 1907. The superstructure masonry was started in August and completed in December, 1907. The temporary pavement of the roadway was completed and the highway opened to traffic in March, 1908.

The 31st Street Viaduct, between Eighth and Ninth Avenues, is 800 ft. long and 40 ft. wide. It is a single-deck structure supported on the retaining wall on the south and on steel columns on the north. The columns are placed between the tracks and in the platforms at intervals varying from 19 ft. 5 in. to 43 ft. 1 in. from center to center, and, on account of the track layout, the twelve easterly and five intermediate columns are placed in a line askew to the viaduct and distant 32 ft. 6 in. (maximum) north of the north house line.

The deck framing is made up of riveted longitudinal stringers spaced about 5 ft. 5 in. from center to center, each built up of one 24 by $\frac{3}{8}$-in. web-plate and four 6 by 6 by $\frac{1}{2}$-in. L's, and face-connected at the ends to the webs of the transverse girders, which, in turn, rest at the south end on steel I-beam grillages set in pockets left in the retaining wall for the purpose, and top-connected to the columns or face-connected to the longitudinal girders on the north end. Each of these transverse girders is built up of one web-plate varying from 62 by $\frac{1}{2}$ in. to 96 by $\frac{9}{16}$ in., with four flange L's varying from 6 by 6 by $\frac{5}{8}$-in. to 8 by 8 by $\frac{3}{4}$-in., and from two to four cover-plates 15 and 18 in. wide.

The columns are made of two 15-in. channels, double latticed, and reinforced in some instances by 15-in. cover-plates. They vary in length from 30 ft. 8 in. to 43 ft. 2 in. There are riveted plate and angle brackets at all girder connections to columns. The columns are braced, longitudinally of the viaduct, in pairs, by a battened diagonal bracing system with top and bottom latticed struts, thus making them almost equally strong in each direction.

For a length of about 400 ft. at the east end, the viaduct is opposite the U. S. Post Office Building, and as it has been determined to support certain minor features of the building entrances and areas on this viaduct, the latter has required strengthening.

This strengthening has been accomplished by introducing a diagonal bracing system, which is connected to the transverse girders at the top, and to the lowest point of attachment of the original longitudinal column bracing about midway of the column length at the bottom. A lateral system has been introduced in the plane of these diagonals. By the introduction of the diagonal system referred to, the columns were made stronger in a north and south direction than in the opposite direction. Hence, where the difference in value under actual loading conditions required it, the longitudinal bracing was modified and extended down the column sufficiently to compensate.

Between the deck stringers, semicircular spandrel concrete arches were turned, and the deck was water-proofed and completed in the manner hereinbefore described for the 31st Street Viaduct between Seventh and Eighth Avenues, except that the completion of the north sidewalk was a part of the viaduct work, and therefore a superimposed concrete retaining wall or bulkhead was built monolithic with the northerly arches on the north house line to within 6 in. of the top of the sidewalk in order to retain the fill. The deck water-proofing is turned up the back of this wall. Tie-rods were provided at intervals of about 7 ft. between the stringers in order to take up the thrust of the deck arches. The contractors requested permission to omit these, on account of the nuisance of constantly readjusting forms, and were permitted to omit all but those in the north panels. A timber frame wood fence was erected on the north house line and attached to the superimposed bulkhead wall.

The excavation to sub-grade and the construction of the retaining wall were executed under another contract.

PLATE LXII.
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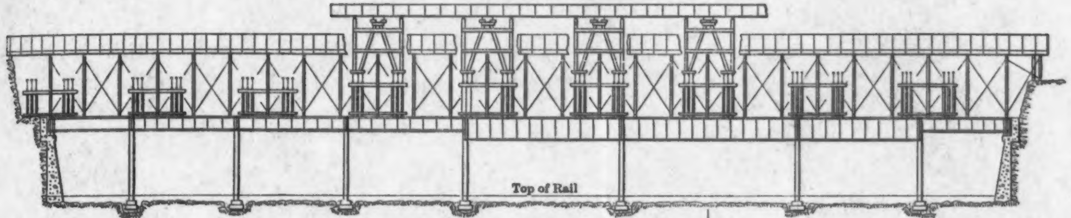
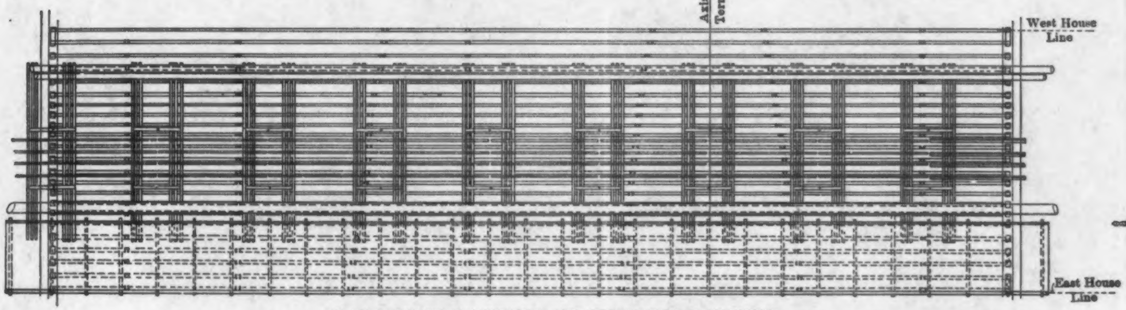
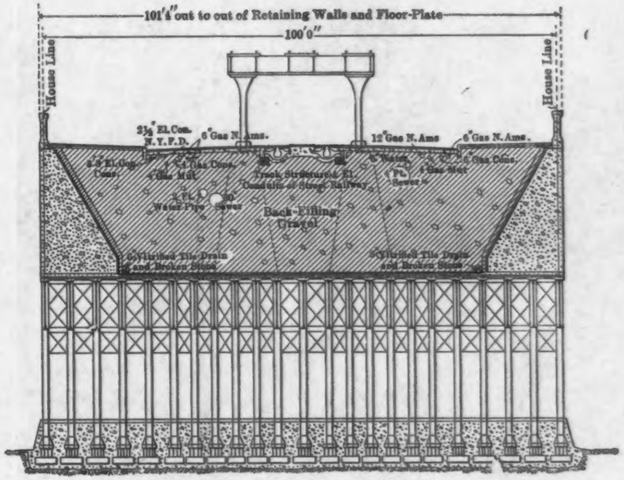
PENNSYLVANIA R. R. TUNNELS: TERMINAL STRUCTURES.



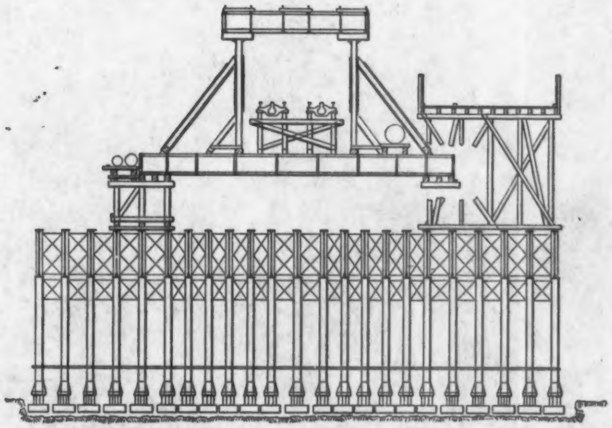
SIDE ELEVATION LOOKING WEST



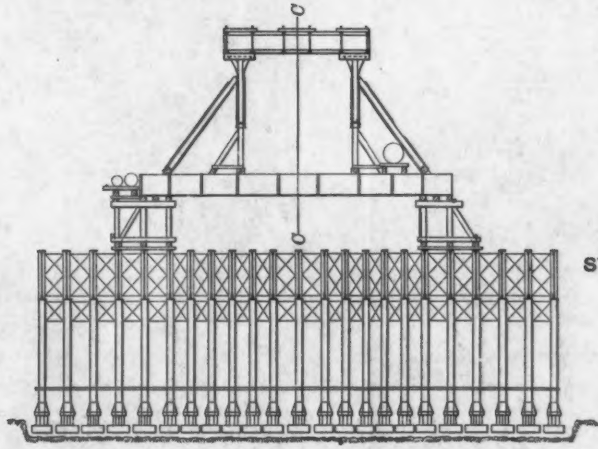
PLAN SHOWING FALSEWORK AND STEELWORK IN POSITION



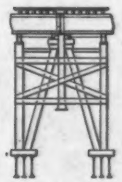
SECTION SHOWING COMPLETED WORK



SECTION SHOWING FALSEWORK AND STEELWORK IN POSITION



SECTION SHOWING FALSEWORK AND STEELWORK IN POSITION



SECTION "C-C"

STEEL VIADUCT UNDER 9TH AVE.

PLAN AND SECTIONS
SHOWING RELATION OF TEMPORARY TO
PERMANENT STRUCTURE

The excavation for the twenty-nine column foundations of this viaduct was started in September, 1907, and completed in July, 1908. The foundations were started in October, 1907, and completed in July, 1908. The steel erection was started in June, 1908, and completed in March, 1909. The deck masonry was started in April, 1908, and completed in April, 1909. The highway was restored to traffic by the completion of the temporary pavement in December, 1909.

The 33d Street Viaduct, between Eighth and Ninth Avenues, is 800 ft. long and 43 ft. wide, and is identical in type with the 31st Street Viaduct between Eighth and Ninth Avenues, except that the columns are all in the same straight line (approximately on the south house line).

The excavation to sub-grade and the construction of the north retaining wall were executed under another contract.

The excavation for the twenty column foundations of this viaduct was started in October, 1907, and completed in December, 1908. The foundations were started in February, 1908, and completed in January, 1909. The steel erection was started in March, 1908, and completed in May, 1909. The deck masonry was started in April, 1908, and completed in June, 1909. The highway was restored to traffic by the completion of the temporary pavement in July, 1909.

The 31st Street Viaduct, west of Ninth Avenue, is 200 ft. long and 40 ft. wide, and is similar in type to the 31st Street Viaduct between Eighth and Ninth Avenues. It is opposite the site of a proposed Express Building, and has been designed so that an intermediate floor connected with such a building may be constructed at some future date.

To provide a suitable depth of story beneath the roadway deck, the transverse girders of the latter are placed in pairs, one on each side of the columns, with riveted diaphragms at the stringer connections. By this arrangement the transverse girders were reduced to 48 in. in depth, but this design resulted in erection difficulties not encountered in the more simple types used elsewhere.

The excavation to sub-grade and the construction of the south retaining wall were executed under another contract.

The excavation for the eight column foundations of this viaduct was started in March and completed in August, 1909. The foundations were started in April and completed in August, 1909. The steel erec-

tion was started in May and completed in September, 1909. The deck masonry was started in August and completed in November, 1909. The highway was restored to traffic by the completion of the temporary pavement in January, 1910.

Loads.—In determining the weight of the structures, for the purpose of calculating the strains, the weight of masonry floors has been assumed at 140 lb. per cu. ft. The decks immediately beneath 31st and 33d Streets have been designed to carry concentrated live loads in accordance with the diagram, Fig. 2, placed so as to give maximum strains in all parts of the structure.

Longitudinal spacing for loads *"A"* 6½ ft. and 24 ft., alternately.
Longitudinal " " " *"B"* 20 ft. apart.
All loads to be placed so as to produce the maximum effect on all parts of the structure.
Add 25% to the live loads indicated by Fig. 2 to compensate for impact and vibration.

LIVE-LOAD DIAGRAM FOR UPPER DECK OF 31ST STREET AND 33D STREET BRIDGES.

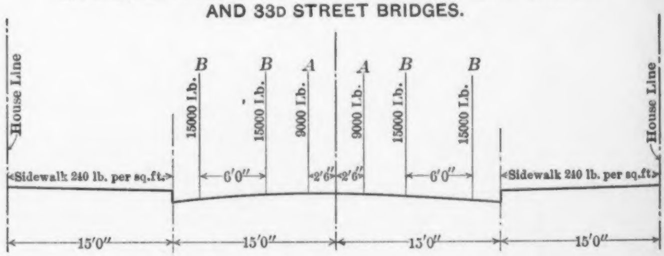


FIG. 2.

In addition to the live loads indicated by Fig. 2, the upper decks of the 31st and 33d Street bridges have been designed to sustain (together with the weight of the structure) a dead load of fill and pavement equal to 135 lb. per cu. ft.

The lower decks of the 31st and 33d Street viaducts between Seventh and Eighth Avenues have been designed to carry a live load of 240 lb. per sq. ft., uniformly distributed.

To compensate for the effect of impact and vibration, 25% of the maximum strains resulting from the above mentioned live loads have been added thereto.

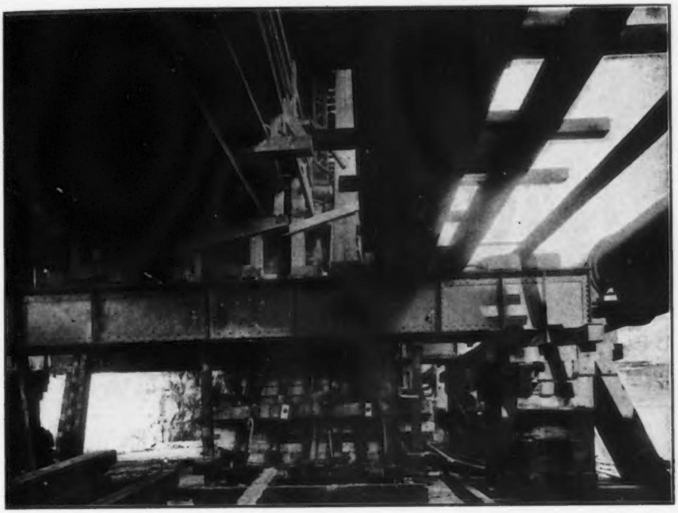


Fig. 1.—Falsework and Concrete Pier for Support of Elevated Railway, Ninth Avenue.

Fig. 2.—Ninth Avenue Bridge During Construction.

The Ninth Avenue Viaduct.—The Ninth Avenue Viaduct is 376 ft. long and 100 ft. wide, and extends across the terminal from the south curb line of 31st Street to a point about 110 ft. south of 33d Street. It supports eighteen columns of the elevated railway structure. The franchise required that the minimum depth from the street surface to the top of the structure should be 19 ft. For the reasons hereinbefore stated, it was determined to restore the highway by back-filling over the viaduct roof; hence the latter was designed to support the weight of the back-fill in addition to the weight from the elevated railroad structure, and a uniform live load of 300 lb. per sq. ft. of street surface. The column bents are located wherever practicable between the tracks, but, owing to the relation of the viaduct location to the track layout, the resulting spans vary from about 33 to about 68 ft.

The contract required that the highway and elevated railway traffic should be maintained in service during the construction of the viaduct, hence it became necessary to design the structure so as to simplify its erection. Owing to the comparatively long spans and the heavy loads, it was decided to erect a top-bearing, plate-girder structure, all girders to be set longitudinally, and spaced 5 ft. from center to center, except under the foundations for the elevated railway columns, where they were to be spaced 4 ft. from center to center. The columns in all bents were to be similarly spaced.

The extreme north and south ends of the structure rest on abutment-wall bridge seats. Lateral stability is provided by introducing a horizontal lateral system between the top flanges of each marginal pair of girders, also by introducing substantial cross-frames between the girders and at the tops of the columns.

The floor-plate is made up of 6-in., 12¼-lb. I's, laid transversely, and 6 in. from center to center under the superimposed retaining walls and elevated railway columns, and 8 in. from center to center elsewhere, spanning at least three girders, and with broken joints. These beams are encased in concrete, the floor-plate being similar to that in the "Easterly Portion," hereinbefore described.

The foundation piers, of 1:2:4 Portland cement concrete, 5 ft. square at the top and 12 ft. 6 in. square at the base, are built as monoliths, from the top of the floor-plate to the base of the elevated railroad columns, just below the surface of the avenue. The resulting load on the structure at the base of these foundations is approximately

4 000 lb. per sq. ft.; the superimposed load elsewhere on the viaduct is about 3 000 lb. per sq. ft.

Superimposed retaining walls extend from the floor-plate to the street level on both faces of the viaduct; the basin thus formed is water-proofed, covered with masonry, and contains the back-filling.

Each viaduct column is built up with two 15-in. double-latticed channels, and from two to eight cover-plates, 15 in. wide. Each is provided with riveted plate and angle diaphragms at top and bottom, cap-plates, and riveted plate and angle knee-brackets at top, connected to girders and riveted plate and fitted stiffener angle bases; also clip angles for the attachment of the fender curb. The columns with least loads bear directly on cut granite cap-stones, underpinned to solid rock by 1:2½:5 Portland cement concrete piers. The more heavily loaded columns bear on steel I-beam grillages, underpinned to solid rock by 1:2½:5 Portland cement concrete piers. The column bases are secured to the granite cap-stones by two 1¼-in. fox-bolts, 12 in. long, and to the grillages by four ⅞-in. bolts in each column base.

The viaduct girders are 6 and 9 ft. deep, and each is built up of one web-plate with four side-plates, where required, four 6 by 6-in. or four 8 by 8-in. flange angles and from two to twelve cover-plates, 16, 18, and 20 in. wide. Where the girders change in depth from 9 to 6 ft., a riveted plate and stiffener angle seat, double-spliced to the webs and milled to fit the bottom flange angles, is provided on the ends of the 9-ft. girders over the column bearings. Connecting plates are provided on the top flange at one end of each girder and are riveted up to the abutting girder.

On the abutment walls the girders bear on cast-iron pedestals, or steel channel bolsters with top and bottom riveted plates, which, in turn, rest on the cut granite bridge seat.

The scheme for the support of the highway and the elevated railway structure, during the erection of the viaduct, required that a central core of rock be left in place, longitudinally, until the construction of the east and west margins of the permanent viaduct, for a width of about 28 ft. on each side, could be completed; hence the permanent bridging was erected on the east and west margins of the structure, beginning at the north end, and the vertical supports for the falsework were transferred to this permanent bridging. Then the excavation was done, after which the intermediate section was

constructed. The falseworks were arranged so that the foundations for the elevated railway columns could be completed without disturbing them, and they were removed as rapidly as the completion of the permanent foundations permitted.

The columns are encased in continuous concrete fender-walls, with battered faces, from the base of each column to 4 ft. above the top of rail. A reinforcing mesh is placed within 1 in. of the faces of these fender-walls in order to toughen the surface and reduce the tendency to check. There are refuge openings in the fender-walls at intervals of about 25 ft.

The excavation for the 161 column foundations of this viaduct was started in September, 1908, and completed in July, 1909. The foundations were started in October, 1908, and completed in July, 1909. The steel erection was commenced in January, 1908, and completed in August, 1909. The superstructure masonry was started in November, 1908, and completed in September, 1909. The back-filling for the restoration of the roadway was commenced in April, and completed in December, 1909. The elevated railway was transferred from temporary to permanent foundations from time to time as the latter were completed. These foundations were started in November, 1908, and completed in August, 1909. The highway was restored to traffic by the completion of the temporary pavement in January, 1910.

The specifications for the viaducts did not vary much, in respect to materials and workmanship, from those quoted in Appendix A. Extracts from the specifications for the manufacture of the steel for the viaducts are given in Appendix B.

Substructures.

All work below the track level between the marginal retaining walls, from the east side of Tenth Avenue to the west side of Seventh Avenue, except the viaduct foundations, was included in the Substructures Contract, the principal features of which were: Pipe and express trucking subways, elevator pits, a complete under-drainage system, a traction conduit system, and the foundations for the Station Building and the U. S. Post Office Building.

Subways.—Due to the fact that the Station Building is superimposed over the tracks in such a manner that complete provision

for supply and discharge service lines could not be made advantageously within the building itself, and due to the necessity for the installation of a very extensive yard service system, pipe subways are provided beneath the tracks, running across the yard at intervals of about 400 ft., one of them leading directly from the sub-basement of the Service Building. These cross-subways are built, in some cases, for trucking subways, and are connected to a longitudinal subway extending from Seventh to Ninth Avenues, to provide for the transfer of express matter between the trains and the Express Building site west of Ninth Avenue, and also to provide for the transfer of certain mail matter between the trains and the Post Office site west of Eighth Avenue.

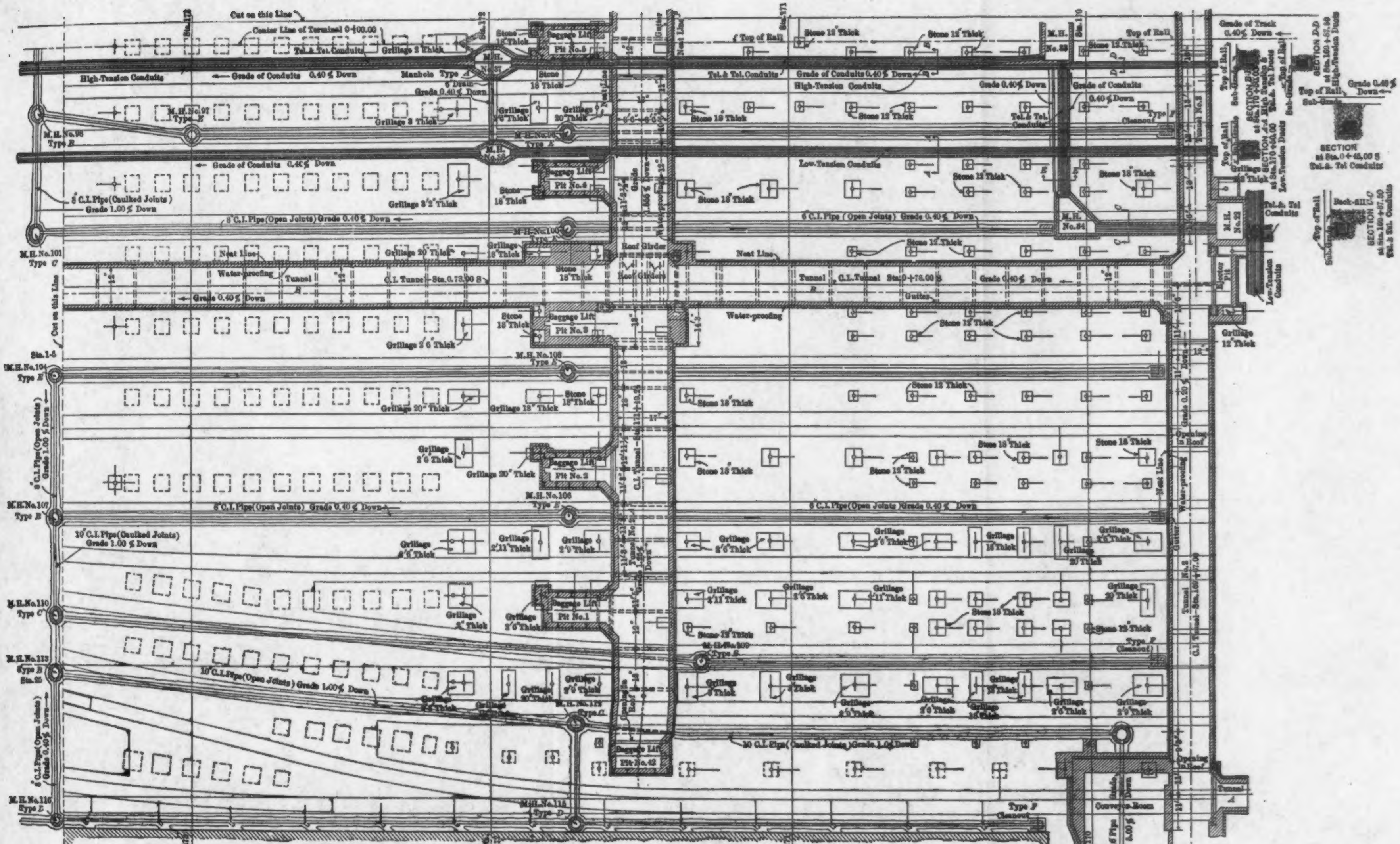
The pipe subways vary in clear width from 4 to 12 ft. and in clear height from 10 to 15½ ft. They contain mains for fire service, water supply, car heating, air-brake testing, the operations of interlocking, the heating of the Station Building, also certain soil pipes and rain-water leaders from the Station Building, drainage lines from the yard buildings, electric conduit feeders for yard, platform, and subway lighting, and for the operation of the electro-pneumatic interlocking plant. These service lines are carried beneath the roof of the trucking subways and above the head-room for trucking.

For the discharge of soil drainage from the yard buildings, and for that portion of the soil drainage from the Station Building which could not be discharged by gravity, ejectors are placed in pits provided for the purpose; these pits are connected to and form a part of the subway system.

The cross-trucking subways are 17 ft. wide in the clear and have a height of about 12 ft. The longitudinal subways are 12 ft. wide in the clear and about 13 ft. high. Beneath the pipes there is clear head-room of 8 ft. for trucking.

The subways are of reinforced concrete of box section, the roofs and side-walls being designed to support the track bed and train loads, and the whole cross-section to resist hydrostatic pressure, due to an assumed head of water measured below the bottom of the under-drainage system, which is at an average depth of 1 ft. 6 in. below the subway roofs. In order to reduce the superimposed dead load to a minimum, the subway roofs are placed at sub-grade, 2 ft. below top of rail. The train loads were reduced to an equivalent uniformly-dis-

PLATE LXIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1164.
FRANCIS AND O'BRIEN ON
PENNSYLVANIA R. R. TUNNELS: TERMINAL STRUCTURES.



GENERAL LAYOUT, FOR SUB-STRUCTURES

tributed live load per square foot of subway roof. Subway roofs beneath platforms are of lighter section, but are strong enough to provide for such loads as may come upon them due to the use of the space below the platforms for branch service lines.

The reinforcement of the subways is of plain, square, merchantable rods, having a permissible unit stress of 16 000 lb. per sq. in., and spaced at intervals of 6 in. from center to center. Similar bars were set longitudinally and wired to the transverse bars wherever practicable, for reinforcement against temperature effects and shrinkage. These temperature bars are at intervals of 12 in. from center to center throughout the cross-section, a single system being used in the floors and side-walls and a double system with alternate spacing in the roof. The interior face of the reinforcement is 1½ in. back of the finished interior face of each subway. The subways are completely enveloped with six-ply pitch and felt water-proofing, and protected by masonry. Where conduit banks cross the subways, they are constructed in reinforced concrete troughs just below the subway roofs. The side-walls of these troughs are designed as reinforced concrete girders, and the floor slabs of the troughs are suspended from them. Many pipes pass through the walls of the subways, and in order to provide for putting these in after the subways had been constructed, and to insure a water-tight job on completion, pipe sleeves, made up of pipes of varying diameters, threaded on the outside and each fitted with two cast-iron screw flanges, with lead washers, are set in the walls and clamped to the water-proofing, a sufficient space having been allowed between the external perimeter of the pipes and the internal perimeter of the sleeves to permit of caulking the external joint between them after placing the pipes.

Numerous openings have been left in the roofs of the subways for pipe branches under platforms, and elsewhere, for connection with surface pipe trenches. The presence of foundations, conduit lines, drainage lines, etc., adjacent to and connected with the subway system, made the execution of some portions of the substructure work a very painstaking task.

Pockets have been left about 2 ft. below the roofs of the pipe subways at intervals of 12 ft. from center to center, thus providing bearings for the pipe-hanger beams, each of which is made up of two 6-in., 8-lb. channels, back to back. In the trucking subways, 9-in.,

21-lb. I-beams are built into the roof section, with their bottom flanges flush with the ceilings. Three-piece wedge forms were set up over these I-beam flanges and withdrawn on the completion of the work, thus leaving the flanges free and clear for the attachment of the pipe hangers.

In general, the method of procedure in the construction of the subways was as follows:

A trench was excavated and a concrete floor base was placed, ready for water-proofing; then backing-walls, varying in height from 2 ft. to the full height of the subway, according to the conditions encountered, were built, usually for stretches of 100 ft. at a time. Owing to the nature of the rock and the presence of deep pockets of earth, the trenches were in some cases excavated from 5 to 10 ft. wider than required by the drawings, and in these instances, after experimenting with various heights of backing-wall, it was finally determined to build the backing-walls in the first stage to a height of about 4 ft., thus forming with the floor base a basin, which was then water-proofed. After completing this first stage of water-proofing, the reinforced concrete floor was laid with battered margins arranged to obtain the effect of a flat inverted arch thrusting against the side-walls after the latter were completed. Gutters were provided in the floors at one wall angle, to carry off any water which might accumulate from pipe leaks or otherwise. After the reinforced concrete floors had set, a four-piece collapsible timber form, about 30 ft. long, with suitable lagging on its external perimeter, was set up over the floor and adjusted by wedges and keys to the internal dimensions of the subway. The reinforcement was placed at the proper distance from this form, and secured in place by suspending it from scantlings blocked up on the roof of the form. The side-wall reinforcement was bent at the bottom to conform to the above described battered faces of the floor. The outside forms for the walls were constructed separately on the backing-walls above described, and were braced to the sides of the trenches, after which the side-wall and roof concrete was placed as a monolith. The longitudinal reinforcement was extended beyond each section, and lapped for continuity. After the tube concrete had set sufficiently, the external forms were removed, the water-proofing was completed, and the masonry protection was placed. After a sufficient time had elapsed to insure the thorough set of the side-walls

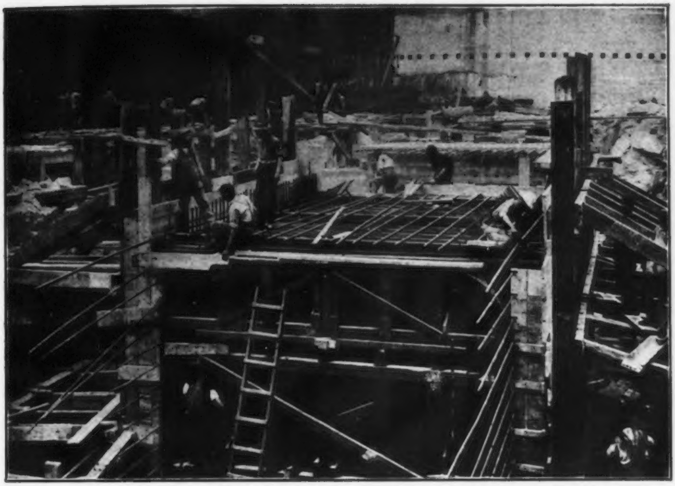


FIG. 1.—TRUCKING SUBWAY DURING CONSTRUCTION.

FIG. 2.—TRUCKING SUBWAY DURING CONSTRUCTION.

and roof, the interior form was pushed ahead and made ready for the next section.

Owing to the great amount of time consumed in placing concrete backing-walls in open trenches, the contractors were permitted to substitute terra cotta tile backing above the 4-ft. wall placed in the first stage. A concrete cover 4 in. thick was placed over the roof water-proofing throughout.

Elevator Pits.—Elevator pits have been provided for the baggage, mail, and express lifts. Nine are connected directly to the main cross-trucking subway just east of Eighth Avenue, two are connected with that subway by a branch at its north end, and two others, just west of Seventh Avenue on the north side of the terminal, are inter-connected by a special trucking subway with a branch connection to the easterly pipe subway.

These lift pits are open at one end and at the top, hence a steel stud and concrete wall structure with reinforced concrete floor was adopted. The floors of the pits are about 5 ft. below the floors of the trucking subway. The pits are 8 ft. wide, 15 ft. 4 in. long, and vary in height from about 18 ft. to 20 ft. The floors and walls are water-proofed with six-ply pitch and felt. The lifts are of the standard plunger type, and the plunger castings are made up of stud rings and clamping rings; to insure tight work, the floor water-proofing was cut to fit the studs on these castings and clamped in place.

The reinforcement of the floors is of $\frac{3}{4}$-in. plain, square, merchantable rods, laid transversely at intervals of 6 in. from center to center, with special framing around the plunger castings. This floor was designed to resist the hydrostatic pressure due to a head of water measured from the bottom of the under-drainage system. The top surface of each pit floor has been graded to a semicircular sump at one end of the pit and on its axis. This sump has a radius of 12 in. and is 6 in. deep. The wall framing is of 15-in. I-beams set vertically, spaced at intervals of about 4 ft. 6 in. from center to center, connected at the top with 15-in. I-beam curbs, and provided with clip angles at the bottom for anchorage. The side-walls of the pits are of concrete, 18 in. thick, finished flush on the inside with flanges of steel studs, water-proofed on the outside, and backed up with masonry.

Chases 18 in. square have been left in the end-walls of the pits for pressure pipes; these walls are normally 3 ft. thick.

Many of the pits are located between the Station Building columns, so that, in some instances two, and in other instances four, of these columns are founded below the floors of the pits and encased in their walls. The entrances to the pits are flared at 45°, these flares measuring 4 ft. on the side; and riveted plate-girder lintels are built into the subway roof to support it across these flared openings.

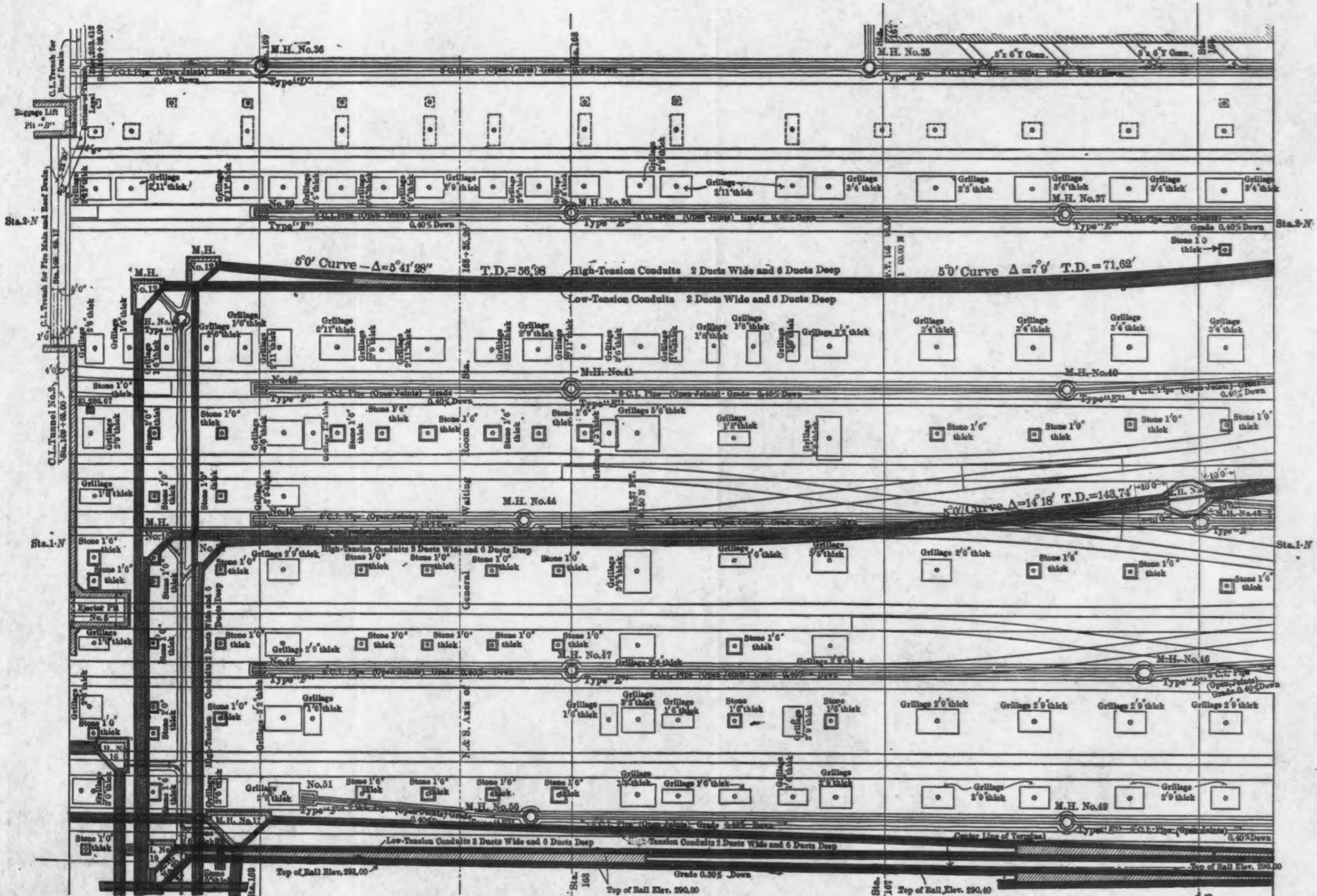
The presence of the Station Building column foundations and the necessity for setting these columns as a part of the lift pit structures made the construction of the latter quite complicated in many instances. To avoid too much delay in the construction of the pits, the Station Building columns in question were spliced just above subgrade, and the lower sections were manufactured and delivered to the substructures contractors and erected by them, thus facilitating progress in the construction of the pits.

In general, the construction of the lift pits proceeded about as follows:

The pits were excavated; a base course of concrete was laid; the concrete facing was carried up against the face of the ledge where the pits were wholly in solid rock, or backing-walls were constructed where the pits were partly in earth, to about the level of the adjoining subway floor base. The basin thus formed was water-proofed, after which, the Station Building column foundations were set, and the lower lengths of these columns were erected. A concrete base, of the width of the side-walls, was placed and on it the side-wall studding was erected. Then the reinforced concrete floor was immediately completed; after which, the side-wall masonry was placed, the waterproofing completed on the outside wherever practicable, and backed up with masonry. In some instances it was necessary to complete the backing-walls and water-proofing before the side-wall studding was erected.

Under-Drainage System.—The summit of the track grades in the terminal area is about 10 ft. below mean high water and about 35 ft. below the general sewer level, and a considerable portion of the terminal yard west of Eighth Avenue is open to the weather.

An elaborate under-drainage system is provided, that portion under the covered area being designed to dispose of seepage from beneath



GENERAL LAYOUT, FOR SUB-STRUCTURES

the enclosing retaining walls, from fissures in the ledge, water from springs, and drip from equipment and platform surfaces. An estimate of the probable maximum quantity of water from these sources, based on experience with somewhat similar conditions, formed the basis of the design for that portion of the drainage system under the covered area.

Open-joint, cast-iron, drain pipes, varying from 6 to 12 in. in diameter, are laid in concrete cradles longitudinally of the terminal at intervals of about 50 ft. from center to center. The tops of these pipes are about 3 ft. below the top of rail. The open-joint drain trenches are back-filled to sub-grade with clean broken stone to insure the proper leaching of surface-water.

The subway system hereinbefore described divides the terminal area into drainage zones, and the longitudinal drain lines are intercepted by caulked-joint collector drains adjacent to these subways, which, in turn, are extended to sumps, whence the water is pumped to the city sewers. The caulked-joint collector drains vary in diameter from 8 to 24 in. They are also laid in concrete cradles, and at sufficient depth to permit them to pass under the conduit lines and in some cases under the subways.

The longitudinal drainage system is laid at approximately the same rate of grade as the track, and sloped east and west from the summit of grades about 500 ft. west of Seventh Avenue. At the point of beginning of each longitudinal drain line, a Y-branch, embedded in concrete and provided with a removable cap, forms a clean-out. There are intermediate clean-out manholes at intervals of about 200 ft. on these drain lines, and manholes on all collector drain lines at the intersections of the longitudinal drains. Such of the latter manholes as are adjacent to sumps have chambers about 3 ft. deep below the lowest outlet, and are known as sump manholes, the purpose of the deepened chamber being to permit of the accumulation and removal of silt, in so far as practicable, outside of the sumps. All drainage manholes are of New York City standard sewer manhole type, with granolithic top-dressed concrete floors, 8-in. brick walls, galvanized-iron ladder rungs, and cast-iron heads and covers. There are Y-branches in the drain lines directly in front of the enclosing retaining walls, at intervals of 25 ft. These Y-branches are connected directly to weep-holes through the walls wherever practicable. The entire zone

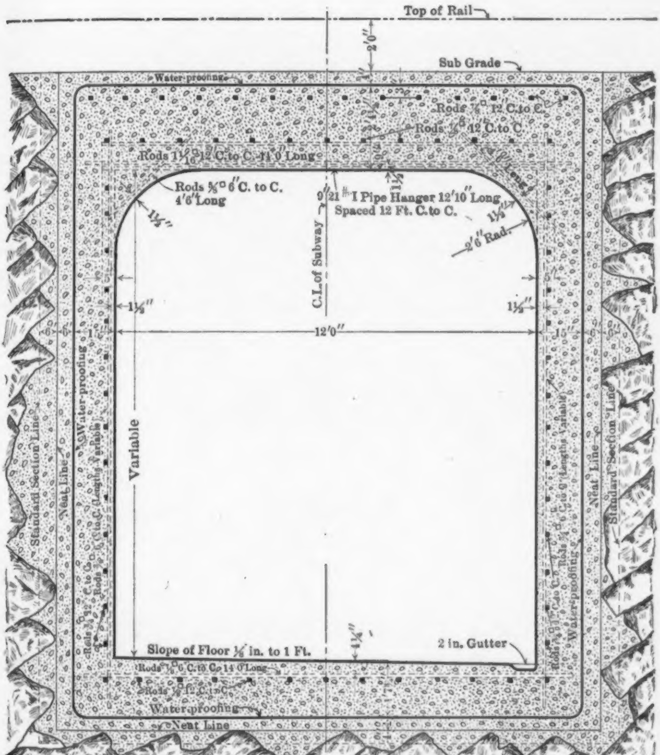
between the summit of track grade and the easterly end of the Easterly Portion contract drains into a sump located just west of Seventh Avenue and south of the 32d Street approach. This sump is a two-story structure, the bottom of which is 22 ft. 6 in. below sub-grade, its roof being at track level. The sump chamber is 23 by 18 by 10 ft., and above this is the machinery room, 23 by 18 by 12 ft. Provision has been made for electrically-operated, centrifugal pumps to be set up on the floor of the machinery-room. This room is connected by a door with the adjacent pipe subway. The suction pits are in the floor of the sump chamber. This sump discharges through a 20-in. pipe into a private sewer built under the west sidewalk of Seventh Avenue, which, in turn, connects with the city sewer at Seventh Avenue and 31st Street.

A zone, immediately west of the track grade summit and south of the longitudinal trucking subway, discharges into a sump having a capacity of 1 000 gal. per min., built beneath the floor of the sub-basement under the south sidewalk of 31st Street in front of the Service Building. This sump has electrically-driven, centrifugal pumps which discharge through an 8-in. pipe into the 31st Street sewer. The remaining area of the westerly slope east of Ninth Avenue empties into a sump, having a capacity of 14 500 gal. per min., just east of Ninth Avenue and south of 33d Street. This sump is a two-story structure, the floor of the chamber being about 28 ft. 6 in. below sub-grade, and the top of the roof about flush with the top of rail.

The sump chamber is L-shaped, the main dimensions being 48 by 22 by 11 ft., and over this is located the machinery-room, the main dimensions of which are 48 by 22 by 13½ ft.

Provision has been made for three electrically-driven, centrifugal pumps (two of which have been installed) with direct-connected motors, the latter being set up on the floor of the machinery-room. This room is connected by a door with the adjacent pipe subway. The suction pits are in the floor of the sump chamber. This sump discharges through a 30-in. pipe into the Ninth Avenue sewer.

The entire westerly slope west of the east line of Ninth Avenue drains into a sump having a capacity of 8 200 gal. per min., which is just east of Tenth Avenue and south of the tunnel portal. This sump is a two-story structure, the floor of the chamber being about 25 ft. below sub-grade, and the top of the roof about flush with the top of



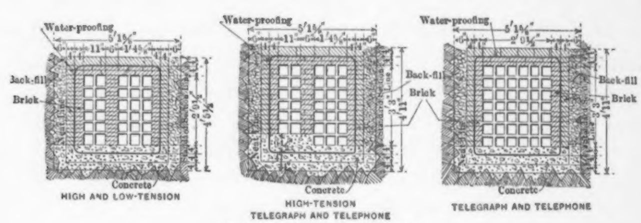
TYPICAL SECTION
OF 12-FT. TRUCKING AND PIPE SUBWAY

Note: In some cases water-proofing was protected on outside of side walls by Terra Cotta tiles instead of concrete as shown.

FIG. 3.

rail. The sump chamber is 40 by 11 by 10½ ft., and over this there is an L-shaped machinery-room, the main dimensions being 40 by 11 by 14 ft. Provision has been made for electrically-operated, centrifugal pumps, to be set up on the floor of the machinery-room. The suction pits are in the floor of the sump chamber. This sump discharges through a 24-in. pipe into the Tenth Avenue sewer.

The sump pit floors throughout are of concrete. The side-walls of the Seventh Avenue and Service Building sumps are of concrete and have a gravity section. The side-walls of the Ninth and Tenth Avenue sumps are of steel studs with concrete between. The intermediate floors and roofs of all sumps are of steel beam framing, with reinforced concrete slabs and concrete beam haunches. The walls of the sumps above the floor level of the machinery-rooms, and the roofs of the sumps, are made water-tight with pitch and felt water-proofing



TYPICAL CONDUIT SECTIONS.

FIG. 4.

protected by masonry. There are vault lights in a portion of the roof of the Ninth Avenue sump to afford light for the machinery-room. There are staircases in the Seventh, Ninth, and Tenth Avenue sumps for access to sub-grade, and the staircase openings in the Ninth and Tenth Avenue sumps are protected by reinforced concrete hoods, the roofs of which are covered with vault lights. Trolley hanger-beams in the machinery-rooms of all sumps facilitate the erection or replacement of machinery, and in the roofs there are hatches, with water-tight covers, for the same purpose.

Conduits.—Two low-tension conduit banks, three ducts wide and six ducts deep, and two high-tension conduit banks, two ducts wide and six ducts deep, are laid in the walls of the tunnels under 32d and 33d Streets east of the Easterly Portion contract, one bank of each class being laid in each tunnel wall, making eight duct banks in all.

FIG. 1.—ELECTRIC CONDUITS DURING CONSTRUCTION.

FIG. 2.—ELECTRIC CONDUITS DURING CONSTRUCTION.

These are continued westward below the terminal sub-grade to points opposite the Service Building, where they are turned southward and connected with splicing chambers in front of the Service Building sub-station.

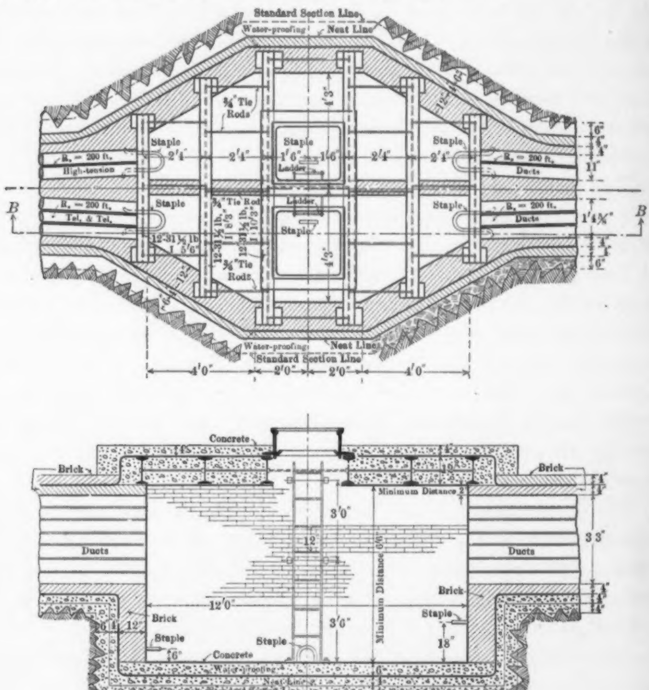
A low-tension conduit bank, four ducts wide and six ducts deep, and a high-tension conduit bank, two ducts wide and six ducts deep, are laid in the north and south walls of the twin tunnels from the North River, making four banks in all. These are connected through splicing chambers at the tunnel portal, and thence extended eastward below the terminal sub-grade to a point opposite the Service Building, where they are turned southward to splicing chambers in front of the Service Building sub-station.

Two banks of telephone and telegraph ducts, each three ducts wide and seven ducts deep, are extended on either side of the core-wall of the North River tunnel portal from a splicing chamber just east of Tenth Avenue eastward below the terminal sub-grade to a point opposite the Service Building, where they are distributed through splicing chambers which connect through shafts, built in the station platforms, with the pipe gallery beneath the Station Building. Connections have also been made through certain splicing chambers to service lines in Eighth and Ninth Avenues. There are splicing chambers on all conduit lines at intervals not greater than 400 ft., and otherwise where the lines change direction.

The ducts are laid in trenches excavated for the most part in solid rock, the tops of the completed banks being about 1 ft. below subgrade. The duct banks are encased in brickwork above a concrete base and completely enveloped in a water-proofing of four-ply pitch and felt, which, in turn, is protected by 4 in. of brickwork.

The original design required that the ducts should be encased in concrete and that all water-proofing protection should be of concrete; but, as it was feared that the act of depositing the concrete encasement would distort the duct bank alignment, and force open the joints, causing plugging of the ducts, it was determined to substitute brickwork, so that the entire masonry of the ducts above the concrete base could be executed by skilled labor. The very satisfactory result obtained justified the change in plan. The splicing chambers have concrete floors, brick side-walls, with brick partition walls in the double chambers, and roofs of steel beams and concrete. They

have manhole heads of cast-iron, with extension tops where required, and double covers. The splicing chambers are placed between the tracks for convenient access. They are water-proofed with four-ply pitch and felt, which is protected by 4 in. of brickwork on walls and 4 in. of concrete on roofs. The floors of these manholes are drained by pipe connections to the under-drainage system.



LONGITUDINAL SECTION B-B
DETAIL OF TYPE "A" MANHOLE
FOR ELECTRIC CONDUITS
SCALE IN FEET
0 1 2 3 4 5

FIG. 5.

Building Foundations.—Between the tracks and in the platforms there are 650 columns for the support of the Station Building. These columns bear on cut granite templates or steel grillages of one or more tiers, underpinned to solid rock by concrete piers varying in

FIG. 1.—ELECTRIC CONDUITS, PIPE SUBWAY, THIRTY-FIRST STREET BRIDGE, AND SERVICE BUILDING, DURING CONSTRUCTION.

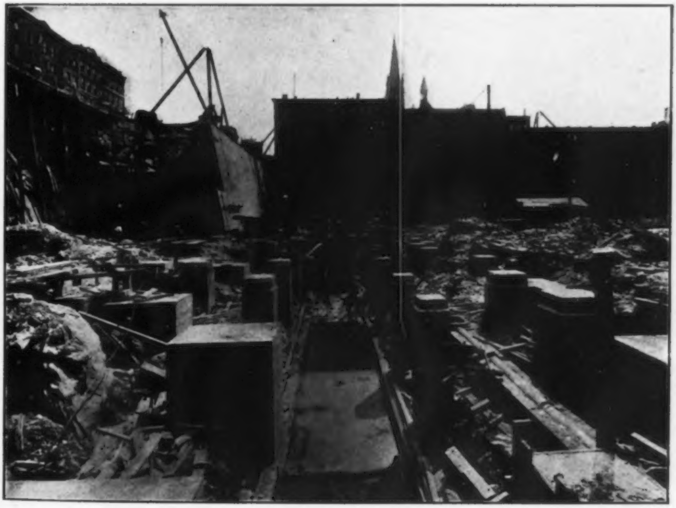


FIG. 2.—PIPE SUBWAY AND FOUNDATIONS DURING CONSTRUCTION.

dimensions from 2 by 2½ ft. to 10½ by 14 ft. The column loads vary from 10.5 to 1 658 tons. Grillage bearings were substituted for cut granite cap-stones where the loads prohibited an economical use of the latter. Many columns are located so that their foundations form an integral part of the other substructures, as in the case of columns surrounding elevator pits, hereinbefore described, and columns at junctions of pipe subways. Many other columns are adjacent to pipe and trucking subways, conduit lines, splicing chambers, manholes, etc., the excavation for which, on account of the nature of the rock encountered, required that column foundations be excavated at least to the depth of the excavation for the adjacent structures, in some cases 20 ft. or more below sub-grade.

The 200 columns for the support of the U. S. Post Office Building, west of Eighth Avenue are located between the tracks and in the platforms, and bear on cut granite cap-stones and steel grillages which are underpinned to solid rock by concrete piers. These foundations are similar in character to those for the Station Building. They vary in dimensions from 2 ft. 2 in. square to 7½ by 13 ft. The excavation for many of these was carried to the bottoms of the trenches of adjacent substructures. The specifications for the substructures, in respect to materials and workmanship, do not vary much from those quoted in Appendix A.

Station Building Steelwork.

The design, fabrication, and erection of the structural steel for the Station Building was one of the most difficult problems of the entire terminal. The work of design was begun in 1902, and the last shop cards were checked in December, 1908. Steel deliveries began in May, 1907, and were completed in April, 1909. Erection began about May, 1907, and was substantially completed in September, 1909.

The first contractors for the manufacture of this steelwork went into the hands of receivers in June, 1907, after delivering about 500 tons of material. They had prepared 7 877 shop drawings, nearly all of which had been checked by the engineers. The receivers completed the fabrication and delivery of about 1 800 tons additional. The manufacture and delivery of the remainder of the material was re-let to another firm of contractors who found it necessary, in order to conform to their shop practice, to make 4 719 new shop drawings for their

work: thus almost 13 000 shop drawings were prepared for the Station Building steelwork, and nearly all of these were checked by the engineers.

The engineers, in making the general design from which the shop drawings were prepared, were for several years in constant consultation with the architects, the committees and representatives of the railroad, and the engineers in charge of lighting, heating, ventilating, and other service details, in order that the steel might be designed to fit the architectural and service requirements, and at the same time conform to the prescribed clearances and permissible column locations at track level. During the period of manufacture many important changes were made in the primary arrangement of certain tracks and features of the building, and these introduced some confusion in the readjustment of drawings already made and occasionally of steel already rolled or fabricated. The drafting organization, however, finally completed all revisions, and the material was properly fabricated and erected.

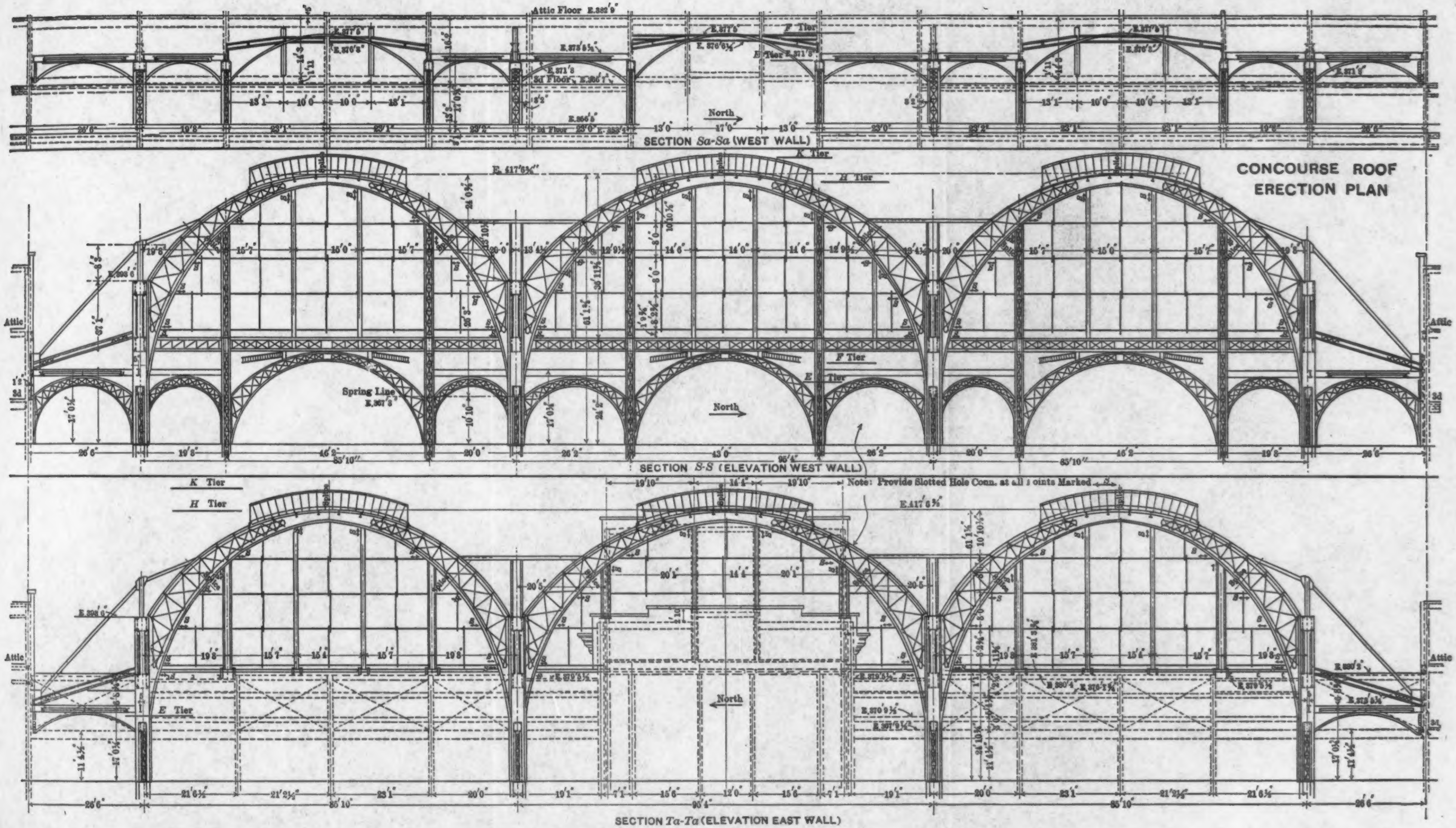
The Station Building covers the site between Seventh and Eighth Avenues and between West 31st and West 33d Streets. It is about 775 ft. long and about 430 ft. wide. It is set back about 19 ft. from the house line of Seventh Avenue, 13 ft. from the house lines of 31st and 33d Streets, and 7 ft. from the house line of Eighth Avenue, thus affording wider sidewalks than are customary. The façades on the streets and avenues rise to a height of about 75 ft. above the curb at the entrance pavilions, and elsewhere to an average height of about 65 ft. above the curb. The portion of the structure enclosing the general waiting-room, the external dimensions of which are 325 by 119 ft., rises in the form of a great lantern 87 ft. above the portions fronting on the streets.

The cubical contents of the Station Building, measured from the track level to the average roof level, is about 40 000 000 cu. ft.

The exterior walls of the building are of cut granite, in solid and ashlar formation, the ashlar being backed up with brickwork.

All interior walls are of brick with face-brick finish, or of brickwork covered with plaster, artificial stone, marble, granite, or combinations of these facings, according to the architectural treatment.

Reinforced concrete floor and roof slabs, with beam haunches of concrete, have been used throughout, except on pitched roofs, where book tiles were laid.


CONCOURSE ROOF
ERECTION PLAN
Attic Floor
North
SECTION Sa-Sa (WEST WALL)
K Tier
H Tier
F Tier
E Tier
Attic
Spring Line
SECTION S-S (ELEVATION WEST WALL)
Note: Provide Slotted Hole Conn. at all Joints Marked S
SECTION Ta-Ta (ELEVATION EAST WALL)

The total estimated weight of the building, adding all live and dead loads together, is 463 158 700 lb., or 231 579 tons.

The building is superimposed over the tracks, which are spaced so that the columns could be placed between them. Owing to the nature of the problem as a whole, but owing particularly to the relation of the building to the track layout, it was determined to adopt, in so far as practicable, the "cage" type of steel structure, with supporting columns founded at or below track level.

The column locations at track level were fixed by the track layout and clearances, which were determined in advance of the preparation of drawings for the Station Building; and, in providing for the support of the building walls above, unusual girder and offset column arrangements were required in many places.

Outline drawings of the building were prepared by the architects and submitted to the engineers, for preliminary determination of column locations, floor gradients below street levels, sidewalk gradients, types of frames for the various sections of the building, stability of cornices, and other details.

The exact dimensions and character of the building masonry were determined by the architects from time to time after the engineers' preliminary structural studies of the various sections of the building were completed. Subsequently, the working drawings of the steel were prepared ready for the manufacturer.

An examination of the outline drawings first submitted by the architects disclosed the fact that the station was made up of many large inter-connected buildings, more or less structurally dissimilar; hence, for convenience and to facilitate progress in design, the problem was separated into its several component parts, namely: the Seventh Avenue Building, the 31st Street Building, the Eighth Avenue Building, the 33d Street Building, the Easterly Train Sheds, the Arcade, the Restaurant, the General Waiting-Room, the Sub-Waiting-Rooms, and the Concourse. These subdivisions were separately assigned to assistants, each in charge of several draftsmen; and the preliminary studies, final designs, and working drawings were prepared, several subdivisions being advanced at one time, and properly correlated.

It was determined that the tier plans should be made on a scale of $\frac{1}{8}$ in. per ft., which was the scale adopted for the working drawings of tracks and all other structures, the purpose being to have all

constructive features of the terminal laid out on a scale which would permit of ready comparison with the track layout. The scale adopted for tier plans was also adopted for sections and elevations. Typical details of columns, girders, trusses, and important connections were prepared on a scale of ½ in. per ft.

As the preliminary studies advanced, a scheme was laid down, and key diagrams were prepared for the guidance of the draftsmen in making the working drawings. These diagrams showed the various tiers, up to the ceiling of the lantern, divided into four equal parts. Each of these parts was numbered in brown ink prominently on its plan for ready identification. The sheets required to illustrate one-fourth of a tier plan on a scale of ⅛ in. per ft. were each 36 by 60 in., allowing a border of 1 in. all around. The ceiling and roof tiers of the general waiting-room lantern were divided into two equal parts. One-half of the two tiers was shown on one sheet of the foregoing dimensions.

The key diagrams indicate the section lines and their lettering, and these lines and letters are correspondingly shown on all working drawings. To illustrate the scope and intent of the vertical sections, additional key diagrams were prepared on which were indicated the cutting lines of the various tiers, and these were all lettered to correspond with the letters chosen for the tiers.

Brief specifications were prepared for the guidance of the designers, and each responsible assistant was provided with a copy.

The following system of column numbering was adopted: The east and west lines of columns were numbered from 100 to 2 000, beginning at the south and running north, the ruling column number being on the extreme westerly line, the numbers increasing eastward on the east and west lines. There were 20 main east and west column lines and 35 main north and south column lines, and, by this system, the approximate location of any column was readily determined by its number. Columns off the main lines were given the number of the nearest lined column with compass point suffixes, as 921-*NE*.

Reactions were recorded, in thousands of pounds underscored, at the ends of all girders and trusses, also at the ends of all beams requiring special connections. The sizes of all beams and the materials for all girders were noted against the pieces on the working drawings. The column material was given in the several column schedules. The material for trusses was shown on typical details of the same.

PLATE LXX.
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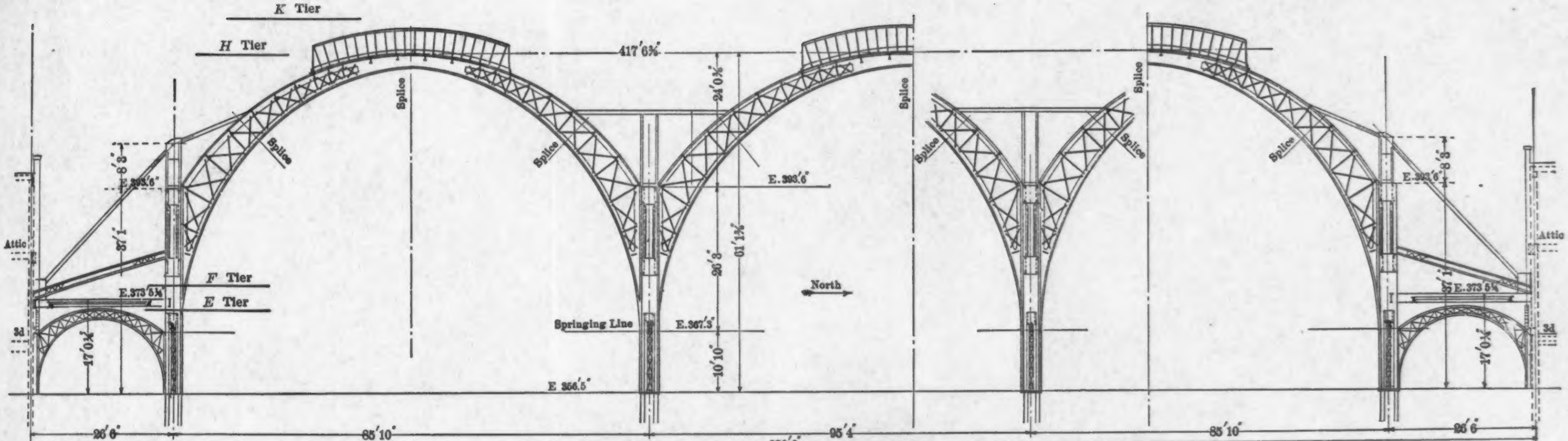
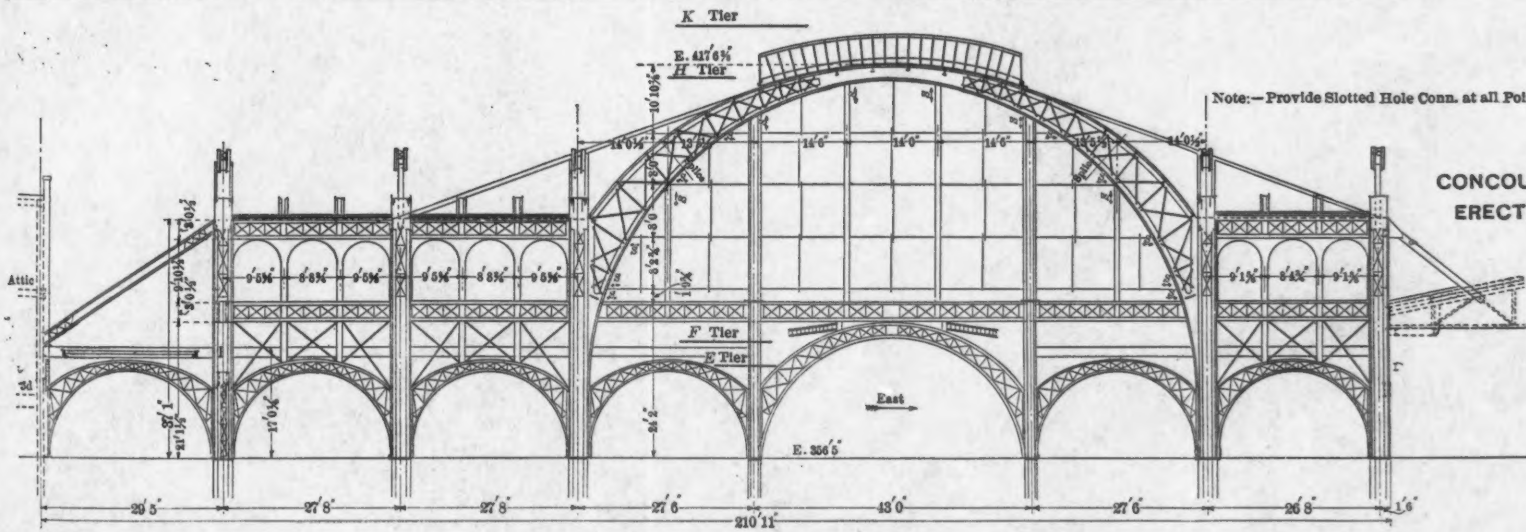


Note:—Provide Slotted Hole Conn. at all Points Marked

CONCOURSE ROOF ERECTION PLAN



SECTION *MM*
(ELEVATION NORTH WALL)

The architectural outline was shown in brown ink on every working drawing.

By agreement with the architects, it was determined, except where the building law governed, that the distance from steel to face of stonework should not be less than 4½ in., and the distance from steel to face of plaster or artificial stone should not be less than 2 in. It was also determined that the distance from the tops of finished side-walls to the tops of sidewalk beams should be 2½ in., and that the distance from the tops of finished floors to the tops of beams should be 5 in., except for the floors of brick-paved driveways, where the distance from the top of the paving to the tops of the beams was 18 in.

The drawings prepared by the engineers comprised 66 working drawings (tier plans and sections), 7 column schedules, 56 sheets of details, and 40 sheets of studies for revisions and additions, a total of 162 drawings. Copies of these drawings were submitted to the architects for check as to relation of steelwork to masonry and finished wall surfaces before they were issued to the manufacturers.

Working drawings were prepared on record sheets of white mounted drawing paper, with a bending-moment diagram shown thereon against each girder and reaction, recorded in the manner previously stated. All the work was checked independently, and each sheet, with the exception of its strain diagrams, was traced on tracing cloth. The strain diagrams of all trusses and bracing were entered in a record book from which the typical detail sheets of these frames were prepared.

All columns were designed to support the total estimated dead and live loads without reduction. The effect of eccentric loads was provided for, and an effort was made throughout to render the structure stable without dependence on masonry walls. Where granite columns occur, however, the architects elected to omit the steel columns which were originally designed to be encased in them; hence, at such points on the façades, the steelwork stops under the granite columns and bears on top of them.

The design of the ceilings of the carriage driveway entrances, at the corners of 31st and 33d Streets and Seventh Avenue, required that the attic floors be supported partly by suspension from the roofs, and this rather unusual method was carried out.

The Seventh Avenue Building crosses the tracks at the wide end of the fan-shaped easterly approaches, and, owing to the track arrangement, the lower lengths of the columns were spaced at varying intervals longitudinally of the building, and many of them were offset north or south of the superstructure columns. Owing to this offset column arrangement, the spans of the girders supporting the main front wall and granite colonnade vary from 16 ft. 2 in. to 53 ft. 4 in. from center to center of columns, and the girders vary in depth from 3 to 10 ft. Certain of the largest girders are of box-section with two web-plates. The granite columns bear on steel I-beam grillages, which, in turn, rest on the main wall girders and longitudinal girders under the granite colonnade beneath the sidewalk. The column line beneath the granite colonnade has no floors attached to it except under the main entrance vestibule. To provide for the general stability of these columns, a horizontal stiffening system is introduced between the girders near the tops of the columns under the granite colonnade, and attached to the lower lengths of the columns under the main façade. A vertical bracing system is also introduced transversely between the girders and columns in these two lines, and is connected up to the columns which are provided outside of the latter under the entrance pavilions. This vertical bracing system is carried down to the column bases. A vertical bracing system is also introduced longitudinally between the columns of one short panel under the colonnade south of the north carriage driveway entrance, terminating in portal bracing above the under-clearance line. A similar panel of bracing is introduced under the colonnade just north of the south carriage driveway entrance, and this latter system is carried down to the column bases. Struts of four angles, double-latticed on all sides, are framed between all other steel columns under the granite colonnade, longitudinally, at approximately the elevation of the lower floor of the Seventh Avenue Building.

The lower lengths of the columns under the carriage driveways on 31st and 33d Streets are braced below the floors to the under-clearance line in tower formation. The columns of the carriage driveways are at intervals of 30 ft. 6½ in. from center to center longitudinally, 46 ft. from center to center transversely in the south driveway, and 50 ft. from center to center transversely in the north driveway. The floors of these driveways slope from the street entrances

FIG. 1.—STATION AREA, FROM EIGHTH TO NINTH AVENUE, SHOWING SUBSTRUCTURES.

FIG. 2.—CONCOURSE ROOF DURING ERECTION.

to the entrance to the baggage-room wagonways at a rate of more than 6%, and these inclined floors are framed in the following manner: Single-web girders, 72½ in. deep, are framed transversely between the columns, and are face-connected to the latter, with the tops of the girders about 12 in. below the top of the finished pavement. Two inclined longitudinal girders, with top flanges 2 ft. 4 in. below the top of the pavement, are framed between the webs of the transverse girders, thus dividing each panel transversely into three equal spans. The floor-beams are 15-in. I's, at about 6 ft. from center to center, framed across the carriage driveways, bearing on top of the inclined girders, and framed at the ends to the webs of the horizontal wall girders, which are framed longitudinally between the columns at suitable elevations to receive the floor-beams and the masonry base course, which change elevation in each panel to suit the inclined floor. The floor-beams are stayed at the intermediate girder bearings by bent plates set on the lower side of the incline, and riveted to the top flanges of the girders and to the webs of the floor-beams near the top of the latter. The tops of the floor-beams are set 13 in. below the top of the pavement.

The vaulted ceilings of the Seventh Avenue vestibule and arcade are constructed of angles suspended from the roof trusses. The ceiling angles at the intersection of the lunettes and the main longitudinal vault of the arcade ceiling have constantly changing planes in both directions, and the development of these taxed the ingenuity of the template maker.

The easterly train-sheds are supported by the wall columns of the arcade shops, the columns of the north wall of the south carriage driveway, and the columns of the south wall of the north carriage driveway. These train-sheds have pitched hipped roofs, and are each 152 ft. 8½ in. long and 115 ft. 6 in. wide. Each has a longitudinal monitor, 91 ft. 7½ in. long and 20 ft. 4 in. wide. The portions of these roofs adjacent to the arcade shops and driveways are depressed between the transverse trusses for a width of 17 ft. and made flat. There are flat connecting roofs with warped surfaces between the train-shed roofs and the walls of the restaurants and the Seventh Avenue Building.

The main transverse trusses of the easterly train-sheds are of the quadrangular type, 115 ft. long, with curved bottom chords and with

top chords laid at roof pitch, except across the monitors, where they are horizontal. These trusses are 30 ft. 6½ in. from center to center, are 14 ft. deep at the center, and have panel points 10 ft. 2 in. from center to center between the flat depressed roofs above referred to. The end panels adjacent to these depressed roofs have solid-plate webs. The end connections on each truss were shipped blank, and drilled in the field, using the column connection angles as templates. The trusses were shipped partly riveted up, with provision for two field splices in the top chords and three field splices in the bottom chords. The web members of the six central panels were shipped loose. The trusses were assembled at the site and completely bolted up, after which they were raised into position by the simultaneous operation of two independent hoists, one on either side of the roof structure. They were supported temporarily at their ends on seat angles riveted to the columns under the connection angles. The trusses were afterward tested for deflection, and correctly lined and leveled, after which the end connections were drilled and riveted. Rivets were substituted for bolts in the truss joints after the roof structure was completely fitted up and adjusted. Vertical sway frames, designed to act as purlins, were connected between the trusses at each panel point. A monitor frame was built up on top of the trusses and sway frames. Rafters, composed of two 6-in., 8-lb. channels, back to back, attached to the top chords of the purlins, divide each roof panel into three equal divisions. Between and flush with the rafters 6-in. channel jack-rafters are framed at intervals of about 5 ft. from center to center. The depressed portions of the roof are framed with 10-in. I-beams at intervals of about 6 ft. from center to center, supported on the bottom chords of the roof purlins on one end, and framed to the girders in the walls of adjoining buildings on the opposite end. This depressed portion of the roof is covered with vault lights; the remainder of the roof is covered with a glass skylight.

The general waiting-room is an immense cathedral clerestory, 320 ft. long and 112 ft. 10 in. wide, from center to center of wall columns, 143 ft. from the floor to the highest point of the ceiling, and 167 ft. from the floor to the highest point of the roof. The floor of this room is about 27 ft. above the top of rail, and a pipe gallery floor is framed beneath it and above the train clearance.

The general waiting-room is enclosed to an elevation about 37 ft.

PLATE LXXII.
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PENNSYLVANIA R. R. TUNNELS: TERMINAL STRUCTURES.

FIG. 1.—STATION BUILDING STEEL DURING CONSTRUCTION.

FIG. 2.—EASTERLY TRAIN-SHEDS DURING CONSTRUCTION.

below the highest point of the roof by carriage driveways on the north and south, restaurants and an arcade vestibule on the east, and the sub-waiting-rooms and concourse vestibule on the west. In the four corners of the general waiting-room structure there are staircase towers, each 18 ft. 6 in. by 20 ft. 6 in. from center to center of tower columns. The ceiling is arched east and west between these towers, and is divided north and south between the towers into three immense vaults which have been constructed of bent steel beams suspended from channel-iron purlins framed between the trusses.

The roof is a series of intersecting gables, three transverse and one longitudinal. A simple mill-building type of frame was adopted for the lofty lantern of this room, with A-shaped main and gable trusses, 19 ft. and 21 ft. deep at the center, and knee-braced to the columns. Ridge trusses, 94 ft. long, and of the full depth of the gable trusses, are framed between the latter in each transverse gable. Longitudinal ridge trusses, each about 44 ft. long, and of the full depth of the main trusses and transverse ridge trusses, are framed between the latter. The valley trusses and groin trusses at the ceiling vault intersections are framed between the ridge trusses and the columns. All trusses have single web systems. The rafters are 10-in., 15-lb. channels, about 5 ft. 6 in. from center to center; bearing on and attached to the I-beam purlins which are framed between the gusset plates of the truss panel points.

The desired architectural effect of massive walls has been obtained by furring the interior face of the general waiting-room in steel framework, faced with stone and artificial stone, the masonry walls being placed on the outside. This method reduced the dead load to a minimum, and provided space for pipes, and also for heating and ventilating ducts.

The steel columns which support the vertical loads from the roof and ceiling are inside of the free-standing architectural columns and 9 ft. 5 in. from the center of the wall columns. The wall columns are directly back of these free-standing columns, and other wall columns are introduced opposite pilasters in the walls of the restaurants and sub-waiting-rooms, below the roofs of the latter, and in the mullions of the semicircular openings of the lantern walls. These mullion columns are in most instances offset from the lower wall columns, resulting in the introduction of heavy girders at the adjoining roof

levels to transfer the loads. Owing to the relation of the general waiting-room to the tracks, certain important wall columns are supported on girders at the general waiting-room floor level, and these girders, which are of full depth between the general waiting-room floor and the pipe gallery floor, transfer the loads to other columns founded at track level.

Wall beams and girders are introduced at the floor tiers, ceiling, and roof tiers of adjacent buildings, and otherwise at intervals of approximately 20 ft. in the height of the wall, for the support of the same.

The frame of the general waiting-room is designed to resist a horizontal wind pressure of 30 lb. per sq. ft. on the entire exposed surface of the lantern. A horizontal lateral system is framed between the main columns and the wall columns, at their tops on the east and west sides of the lantern, and connected up to the tower columns and to a lateral system of frames between the towers at the north and south ends, thus completely banding the top. The wall columns back of the main columns are connected to the latter above the adjoining roofs by a vertical system of bracing through which the stresses at the foot of the knee-braces on the main columns are transferred; and this vertical bracing system is connected at its foot through the adjoining roof trusses or directly to a horizontal system placed in the roofs of the sub-waiting-rooms on the west, and below the roofs of the restaurant on the east. These horizontal systems are in turn connected up to vertical bracing systems in the wall frames at the north and south ends of the sub-waiting-rooms and restaurants, and the effect of wind pressure on the east and west walls of the lantern is thus taken to the ground.

The tower columns are braced vertically and also transversely at every tier above the adjoining roofs, and the end columns of the towers and the intermediate columns of the north and south walls are connected to horizontal trusses built through the roof trusses of the attics over the carriage driveways. Two panels, each of vertical bracing and portal bracing, between the east and west wall columns, about midway of the wall lengths, north and south of the arcade and concourse vestibules, are provided to transfer to the ground the effect of wind pressure on the north and south ends of the lantern.

All wall columns of the lantern are designed to resist wind pressure

FIG. 1.—ARCADE ROOF STEEL DURING CONSTRUCTION.

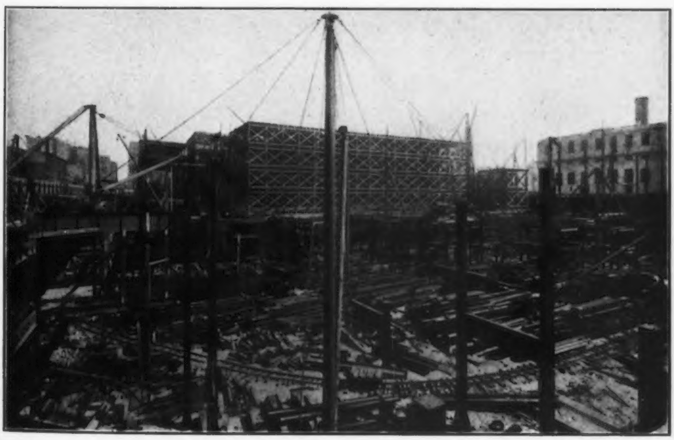

FIG. 2.—FALSEWORK FOR WAITING-ROOM ROOF, AND MASONRY DURING CONSTRUCTION.

in addition to vertical loads, and all are connected at the top and bottom, as described above, to the horizontal systems.

The effect of wind from any direction on the main frame of the lantern was determined and provided for.

The erectors chose to build a timber trestle from track level to roof level inside of the general waiting-room columns, the purpose being to use it first for the erection of the steel and masonry and afterward as a scaffolding from which to finish the ceiling and interior walls.

The erection of the lantern of the general waiting-room was not permitted until the surrounding sub-waiting-room, restaurant, and carriage driveway structures had been erected, plumbed, and fitted up, including the horizontal systems in or below their roofs, provided as above described, to band the foot of the lantern structure. The roof trusses were shipped knocked down, and were assembled in position by blocking above the trestle, a bolt being fitted into every hole in each joint. After the roof was completely fitted up, lined, leveled, measured, and correctly adjusted, rivets were substituted for bolts in all joints.

The concourse roof was a unique and unusual structural problem. It is made up of three barrels, the two outer of 85 ft. 10 in. span and the center barrel of 95 ft. 4 in. span, running east and west and intersected by a cross-barrel of 98 ft. span running north and south, thus forming, over the main concourse floor, a series of three groined vaults supported on steel columns. The concourse roof columns, east and west, are at intervals of 27 ft. 8 in. from center to center for the two bays west of the groined roof, and 26 ft. 8 in. from center to center for the single bay east of the groined roof.

The main roof structure abuts on the sub-waiting-rooms on the east, and is banded by a lower roof, constructed of a series of Guastavino and steel-framed vaults, on the other three sides, which, in turn, connect to the surrounding buildings. The architectural effect of these latter roofs is enhanced by small steel arches framed between the columns below the Guastavino vaults.

The engineers' original design for the concourse roof provided for exposed ties in the outer barrels at the springing line, all parts to be riveted, but, owing to the desire of the architects to omit all exposed ties, the more expensive cantilever arch type, anchored to

the surrounding structure, was adopted for the arches, and single-web trusses with arch effect below the finished roof line, and with the remainder of the trusses extended above the roofs and forming monitors at their intersections, were adopted for the groins.

After the static determinations were completed, the effect of temperature was analyzed and provided for in all anchorage details.

The main columns are 3 ft. square, and some of these have an unsupported length of 68 ft. 9 in. They are made up of four 8 by 8-in. angles, double-latticed on all four sides, with double-latticed diaphragms, placed horizontally, at intervals of about every 10 ft. of the height of the columns, and provided with riveted bases which have vertical diaphragms. The tops of these unsupported lengths of columns have unique details for splicing the upper lengths, which latter are built with branches arranged to fit the arch trusses at the tops and designed to continue the intrados of each arch to the cap on the lower lengths of the columns. The column splice detail referred to was arranged so that the upper length of columns could be slipped on over it and take bearing on the cap of the lower length. The rivets in these splices were driven by the aid of hand-holes in the upper lengths of the columns, and neatly-made plates were tapped on to the columns flush with their faces after the riveting was completed.

Each half of the main cantilever arch trusses was shipped in two sections, with field splices in both top and bottom chords located in the panel on the column side of the anchorage tie connection. At the crown joints ½ in. play was left between the two complete halves of each arch truss, and fillers were provided for adjustment between web connection angles. The main arch trusses throughout the structure have double web systems, with solid plates in the panels near the crown, and double intersecting angle diagonals and double angle radial members in the remaining web panels. The bottom chords are double-laced between the panel points by angle lacing, with angle struts transversely at each panel point. The top chords are covered with riveted plates. The web systems of these trusses are about 2 ft. from center to center; the trusses are about 2 ft. deep, from back to back of angles at the crown, and have a depth of about 6 ft. 7 in., from back to back of angles measured radially at the highest point of the column attachment. Horizontal ties, with vertical

FIG. 1.—CONCOURSE ROOF DURING CONSTRUCTION.

FIG. 2.—CONCOURSE ROOF DURING CONSTRUCTION.

strut supports above the columns, are framed between the center and outside cantilever arches of the three east and west barrels, with attachment to the top chord of the arch trusses at the quarter points. Triangular frames, with similar attachment to the arch trusses, also attached to the columns in the north and south building walls, and strutted back against the concourse columns above the Guastavino dome roofs, form the terminal anchorages of the outside arches of the east and west barrels. Between the columns which support the three east and west barrels, small double-latticed ornamental arches with two webs are framed just above the lower lengths of the columns. Above these arches a system of double-latticed struts, with two webs and ornamental portals, hold the upper lengths of the columns rigidly together. The main cantilever arches of the north and south intersecting barrel were made in two halves, and each half was shipped in two pieces, with field splices in the third panel above the columns. The anchorage ties for these arches are attached much nearer the top than in the case of the other arches hereinbefore described. The stresses from these ties are transmitted through the frames at the tops of the opposite columns, and thence through the triangular terminal anchorage frames to the columns in the Eighth Avenue Building, and in the west face of the concourse roof, on the one hand, and through the medium of frames built between the sub-waiting-room roof trusses into the columns on the east face of the concourse, and in the west wall of the general waiting-room, on the other hand.

The intermediate columns, placed in the mullions of the tympana at the vertical faces of the main concourse roof, have slotted connections at their tops to the bottom chords of the cantilever arches.

The diagonal trusses at the groined intersections are about 17 ft. deep at the apex joints and about 13 ft. 7 in. deep, measured radially, at the knuckles in the top chords. These trusses have redundant members in order to give the desired arch effect below the roof line. They were shipped knocked down, and were assembed at the site, a bolt being fitted in every field hole, after which they were raised into position. One diagonal truss in each panel was assembled complete and designed to support the two halves of the opposite diagonal truss which were framed to it at the apex joint. Between the main truss panel points 12-in. I-beam purlins are framed, and are banded by two equally-spaced steel plate and angle trough gutter

ribs riveted to the top flanges of the I-beams in each bay. The skylight frames of bent T's are mounted on, and riveted to, these gutter ribs.

All arches were completely assembled and fitted at the shop before shipment. Each half of the diagonal trusses was similarly assembled and fitted at the shop. All parts of the roof were joined together in the field without difficulty, except at the apex joints between the diagonal trusses, where it was necessary to substitute some new gusset-plates and drill the connections in the field. This was undoubtedly due to slight inaccuracies in shop work, which might not have been apparent in a less complicated roof.

At the main concourse floor level, a timber platform was erected, and on it three tower travelers were mounted. The roof was erected with these travelers. Tower props, each about 12 ft. square, were built up from the timber platform for the support of the apex joints of the diagonal trusses pending their adjustment.

The erection of the concourse roof was not permitted until the surrounding structures to which it was anchored had been completely erected. The terminal anchorages, with the corresponding halves of the cantilever arches in the two outer barrels of the three-barrel formation, were first erected, and were held by derrick hitches from the travelers until the intermediate column and cantilever arches were placed. The groined intersecting barrel was erected after the remainder of the roof frame had been set up. After the columns had been plumbed and the roof structure lined, leveled, measured, and completely fitted up, all joints were riveted, the first portions completed being the three east and west barrels; the final closure was made in the north and south intersecting barrel.

The concourse roof and all other portions of the Station Building were riveted up without expansion joints. The effect of temperature during the erection of the steelwork of the Station Building was provided for by selecting certain definite lines of adjustment, namely: on the north side of the columns in the north wall of the 31st Street Building, on the south side of the columns in the south wall of the 33d Street Building, on the east side of the columns on the east side of the Eighth Avenue Building, on the west side of the columns in the west wall of the general waiting-room, and on the east side of the columns in the east wall of the general waiting-room.

In these cases the connecting pieces were either shipped blank and drilled in place, or connection angles were made from field measurements, according to the type of connection. Fillers were also provided where required. Riveting of the portion of the concourse floor connecting to the main roof columns was not permitted until after the roof had been riveted up.

All columns were set accurately and all work was laid out with true relation to the governing axes of the principal architectural features. Each feature of the structure was completely fitted up, plumbed, and measured before riveting was permitted.

The many heavy columns developed riveted base details of a very complicated character, oftentimes difficult to manufacture, particularly as regards the fit of the base stiffener angles. In some instances, the removal of these for lack of fit would have required rebuilding entire column lengths. The manfacturers, therefore, were permitted to substitute slab bases, planed on top and bottom, with riveted wing plates and base angles, producing a very satisfactory detail. The slabs vary from 2 to 6 in. in thickness. A series of tests was made at the mill to determine the permissible stress for the slabs, and 15 000 lb. per sq. in. was adopted, the tests showing an elastic limit and ultimate strength equal to the manufacturers' standard material.

The manufacturers divided the structure into twenty subdivisions, numbered from *C*-2 000 to *C*-2 020, inclusive, and all shop drawings were identified by the mark of the subdivision which they illustrated; the material was similarly identified during manufacture, shipment, and erection.

In addition to designing the steelwork and checking the shop drawings, the engineers maintained general oversight of the manufacture, kept records of the progress of the same, estimated the weight of every piece of material for comparison with the scale weight, kept records of shipments and deliveries, and supervised the erection.

Extracts from the specifications for the manufacture of the Station Building steel are given in Appendix C.

Platforms.

All platforms are of reinforced concrete slabs, varying in thickness at the center from 8 to 16 in., spanning between the 16-in. concrete side-walls, and overhanging the latter 1 ft. 8 in. at each edge, which

is 8 in. thick. The overhanging edges have coved soffits of 12 in. radius.

Two intermediate bearing walls of concrete, each 16 in. thick, divide the reinforced slab of the wide platform No. 2 into three equal spans.

The top surfaces of the platforms have granolithic finish, jointed in squares of about 30 in. on a side, and stippled to avoid slippery tread.

Exposed wall surfaces were rubbed after the forms were removed.

The platforms were designed to support a live load of 300 lb. per sq. ft. The slabs are reinforced transversely with steel equal in area to 0.007 of the area of the concrete, and also reinforced longitudinally with the same percentage of steel to resist temperature stresses.

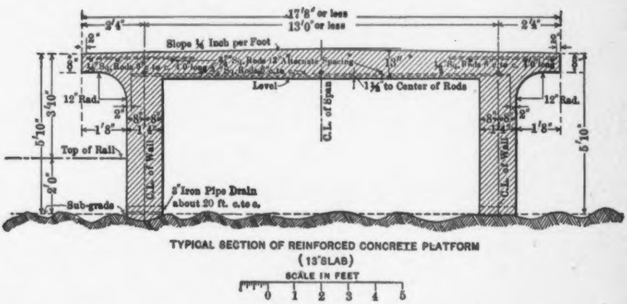

FIG. 6.

The reinforcement is of plain square rods, 6 in. from center to center transversely and ¾ in. above the bottoms of the slabs, with an overlapping set of rods extending into the overhangs near the tops of the slabs.

The longitudinal rods are staggered, one set being placed just over the bottom set of transverse rods and the other near the tops of the slabs and about 12 in. from center to center. The supporting walls are of plain concrete. The platform concrete is composed of 1 part Portland cement, 2 parts sand, and 4 parts broken stone or clean gravel which would pass through a ¾-in. ring. The granolithic top dressing is ¾ in. thick, and is made of 1 part Portland cement and 1½ parts sand, hand-floated, trowelled smooth, and having a stippled finish.

The platforms have numerous openings for elevators, and are fitted with hatches over the elevator pressure tanks. These openings and

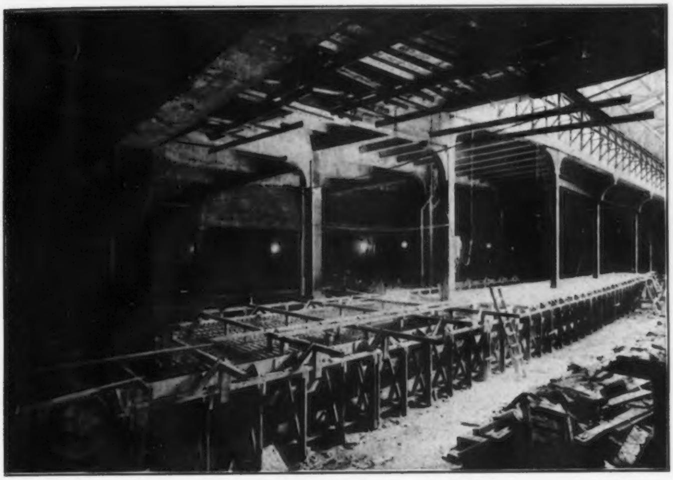

FIG. 1.—PLATFORMS DURING CONSTRUCTION.

FIG. 2.—PLATFORMS DURING CONSTRUCTION.

hatches are framed in steel. The hatch covers are of thin reinforced concrete slabs finished like the remainder of the platform surfaces.

Openings for the installation of signal apparatus, openings for ventilation, fitted with wire screens in cast-iron frames, and openings for access, each fitted with two wrought-iron swing doors hung on rebated cast-iron frames, were built into the side-walls of the platforms.

Bronze sockets with hinged covers were built into the platforms along curved edges at intervals of 4 ft. to receive posts of pipe railing in case the latter is required when the platforms are in service. Bent wrought-iron pipe anchors, threaded for $\frac{3}{4}$-in. bolts, were built into the overhanging edges of the platforms on curves at intervals of 2 ft. from center to center to provide for the attachment of a wooden edge strip, if it is required.

The spaces under the platforms are used as pipe galleries for longitudinal service lines distributed between the pipe subways; and pipe sleeves were built into the platform walls for service taps to the adjacent tracks.

There are weep-holes through the platform walls at sub-grade, for drainage. The platforms were built in monolithic sections, each about 30 ft. long. Their total area is 244 270 sq. ft.

Base Lines and Levels.

It may prove interesting to observe that New York City blocks are not exact parallelograms, although the errors are so small that the irregularity is only observable on the records.

The center line of the terminal east and west, while apparently coincident with the center line of 32d Street, is not exactly so, but rather an average adjustment of the direction of the center lines of 31st and 33d Streets, both opposite the terminal and for blocks east of Seventh Avenue and west of Tenth Avenue. This main base line was determined on the ground, and permanently monumented. Parallel base lines, east and west, as well as transverse base lines, north and south, 100 ft. apart, were established, and all working drawings were related thereto.

A profile grade line for the top of rail was established in connection with the necessary tunnel grades east and west of the terminal. An understanding was reached with the engineers of the city, which fixed the surrounding curb grades in the streets, and these were made

to conform with existing street construction reduced to practicable mathematical lines.

Bench-marks were established from time to time, as found necessary. The datum plane conforms with that of all the other construction work of the company, + 300 being practically mean high water in the harbor.

Engineering Organization.

George B. Francis, M. Am. Soc. C. E., acted as the engineering executive for Westinghouse, Church, Kerr, and Company, with Joseph H. O'Brien, M. Am. Soc. C. E., as Resident Engineer directly in charge of the design and with engineering supervision of the construction.

Westinghouse, Church, Kerr, and Company reported directly on all work, excepting the steel for the Station Building, to George Gibbs, M. Am. Soc. C. E., Chief Engineer of Electric Traction and Station Construction of the Pennsylvania Tunnel and Terminal Railroad Company.

A force of engineers and draftsmen at headquarters designed the work herein described, and another corps was maintained in the field for engineering service in execution. The following persons were connected with the engineering department, and performed faithfully the duties entrusted to them:

Mr. F. F. Skinner, D. Y. Dimon, M. Am. Soc. C. E., H. S. Devlin, Assoc. M. Am. Soc. C. E., W. A. Nial, Assoc. M. Am. Soc. C. E., and C. E. Hunt, Assoc. Am. Soc. C. E.

William R. Webster, M. Am. Soc. C. E., was employed to care for the mill and shop inspection of the steelwork.

All inspectors on the various items of work were under the supervision of the engineers.

The designing of the steel for the Station Building was done by Westinghouse, Church, Kerr, and Company, under an engineering engagement with McKim, Mead, and White, the Architects.

APPENDIX A.

Easterly Portion.

Cement.—All cement used in the work shall be Portland cement furnished by the Railroad Company in accordance with conditions of Article 12 of the contract.

Sand.—Sand for mortar or concrete shall be coarse, sharp and silicious, not containing more than 1.5 per cent. of mica, loam, dirt or clay, or of all combined, and equal in quality to the best Cow Bay sand. If required by the Engineers, it shall be screened.

Broken Stone.—Sound rock excavated from the work may be used if hard, crystalline, and practically free from mica. If a sufficient amount cannot be obtained from the work, sound trap or hard limestone must be furnished. Gneiss from other localities will not be accepted. The rock must be clean when delivered at the crusher. It shall be broken by machine and screened in a rotary screen, which will remove all dust and fragments, which will pass through a hole ⅜ inch in diameter, and all pieces which will not pass through a hole one and one-half (1½) inches in diameter; all fragments between these limits will be retained. In special cases, hereinafter specified, the maximum size will be that which will pass through a hole ¾ inch in diameter.

Mortar and Grout.—In proportioning materials for mortar, grout and concrete, one volume of cement shall be taken to mean three hundred and eighty (380) pounds net, one volume of sand or broken stone shall be taken to mean three and one-half (3½) cubic feet packed or shaken down. Sand and broken stone shall be measured in barrels or rectangular boxes. Measurements in wheelbarrows will not be permitted.

In preparing mortar for brick or stone masonry, the specified amounts of cement and sand shall first be mixed dry to a uniform color. The water shall then be added in such a manner as not to wash out any of the cement and the mixing proceeded with until the mortar is thoroughly mixed and of uniform consistency.

Grout will generally be in the proportion of one (1) part of cement to one (1) part of sand by volume. The materials shall be thoroughly mixed dry and water then added while the mixing proceeds, until the grout is of the required consistency. The mixing shall be continued vigorously, preventing the separation of sand, until the entire amount mixed is used. Grout shall be used about the imbedded steel for filling small voids wherever concrete cannot be properly used and wherever required by the Engineers to insure tight work.

Masonry—Concrete.—Concrete for abutments and masonry tunnels shall be in the proportion of one (1) part of cement to two (2) parts of sand and four (4) parts of broken stone by volume. All other concrete, except that required for grillages, concrete steel floor plates, and

base of granolithic, shall be in the proportion of one (1) part of cement to two and one-half ($2\frac{1}{2}$) parts of sand and five (5) parts of broken stone by volume. The concrete for grillages and concrete steel floor plates shall be in the proportion of one (1) part of cement to two (2) parts of sand and four (4) parts of broken stone that will pass through a hole $\frac{3}{4}$ inch in diameter.

Whenever practicable, concrete shall be machine mixed. The mixing machine shall be a rotary mixer and of a pattern that will mix the concrete in batches and permit the definite measurement of the materials for each batch. When the Engineers consider it impracticable to mix by a machine, it may be mixed by hand as follows: The mixing shall be done on a platform of boards or planks securely fastened together. The mortar shall first be made as hereinbefore specified. The broken stone previously wetted shall then be added and the mortar and stone turned over with shovels until the mortar is uniformly distributed through the mass and every stone is coated with mortar.

The degree of moisture for mortar, grout and concrete shall be at all times as required by the Engineers or their Inspector; in general, mortar shall be plastic, grout shall be fluid enough to be pumped, and concrete shall be of such consistency that it will quake when being deposited, but not wet enough to cause the mortar to separate from the mixture.

Concrete shall be deposited in the work in such a manner as not to cause separation of mortar and stone. It shall be laid quickly in layers not exceeding nine (9) inches in thickness and thoroughly rammed with rammers of such form and material as the Engineers may approve; special shaped rammers will be required for corners and other places where ordinary rammers would not be effective. Compact, dense concrete must be obtained with all the voids between the stones filled with mortar. If voids are discovered at any time, the defective concrete shall be removed and immediately replaced by concrete of such mixture and in such manner as the Engineers may direct.

Contraction joints in concrete formation shall be made where the Engineers may require them. Where columns limit the thickness of "concrete" at face, the cement mortar used in conjunction with metal reinforcement is measured and paid for as concrete only.

When the placing of concrete is suspended, the Engineers may require a joint to be formed in a manner satisfactory to them, so that the fresh concrete when added, may have a bond. Before depositing fresh concrete, the entire surface on which it is to be laid shall be cleaned, washed, brushed and slushed over with grout of cement without sand.

The surface of freshly laid concrete shall be protected from injury in such manner and for such time as the Engineers may require; concrete injured in any manner shall be removed.

Water used in mortar, grout and concrete shall be clean fresh water.

No mortar, grout or concrete which has commenced to set shall be used anywhere in the work. Re-tempering of mortar or grout which has commenced to set will not be permitted.

Forms for concrete shall be substantial and must preserve their accurate shape until the concrete has set. Where the concrete will show in the finished work, the face of the form shall be built of matched and dressed planking finished truly to the lines and surfaces shown on the plans. Adequate measures will be taken to prevent the adhesion of mortar to the forms. Forms which have become warped or distorted shall be immediately replaced. All forms of whatsoever nature required for concrete work shall be furnished, erected and removed by the Contractor whose price for concrete per yard must include the cost of the forms required.

Contractor shall not remove forms for concrete work until the concrete has set up to the satisfaction of the Engineers. Any forms left in the work by direction of the Engineers shall be paid for by the thousand (1,000) feet, board measure, of the completed form measured in the work.

Faces which will show in the finished work shall be true to the form intended and shall be wholly smooth, free of ridges and cavities, due to shortage of mortar at the face.

Exposed faces shall have a facing of mortar two (2) inches thick deposited simultaneously with the corresponding layers of concrete and separated from the concrete by a metal diaphragm of approved form. After the mortar and concrete have been deposited, the diaphragm shall be removed and the materials well worked together by spading and tamping, so as to insure their bonding. In places where this method cannot be used, as the under surface of arches, the same end shall be attained by methods satisfactory to the Engineers. Plastering the face after removing the forms will not be permitted unless otherwise provided. The facing mortar shall be of the same composition as the mortar used in the concrete back of same.

Rock surfaces shall be thoroughly washed and cleaned before concrete is deposited against them. Earth surfaces shall be wetted and compacted by ramming immediately before depositing concrete thereon.

If leaks appear on the surface of the concrete at any time after removing the forms, the Contractor shall remove the concrete through which the water passes and replace it with sound concrete and shall stop the leakage or conduct the water to the floor of the tunnels through channels or pipes in the concrete, or take such other measures as the Engineers may require.

The rough concrete under grillage seats shall be brought up to within two and one-half (2½) inches of the underside of the grillage bearing plates and shall then be top dressed with Granolithic two (2)

inches thick, leaving a joint to be made not over ½ inch thick between the top surface of the Granolithic and the underside of the grillages.

Granolithic shall be laid on a solid concrete base, and shall have two (2) inches total thickness. The base of this Granolithic shall be one and one-half (1½) inches thick, made up in proportions of one (1) part of cement, two (2) parts of sand, and four (4) parts of broken stone, the maximum size of which will pass through a hole ¾ inch in diameter. This base shall be carefully laid and screeded in place to insure a level top surface. Upon the base so prepared, the Contractor will lay a top dressing of grout ½ inch thick. This grout shall be hand floated and troweled smooth to give a durable and true top surface.

Terra Cotta Block Walls.—The terra cotta blocks used for the backing of waterproofing behind the abutments, shall be hollow, porous, terra cotta partition blocks. These blocks must be so burned that their walls will be absolutely porous.

Samples of the terra cotta blocks to be used in the work must be submitted to the Engineers before they are purchased by the Contractor, and all of the blocks used in the work must be sound, of true mold and in conformity with the sample selected by the Engineers.

Terra cotta blocks shall be laid as far as possible on their smaller beds so that the hollow space may be continuous vertically. Joints shall be broken every fourth course as shown on the drawings. The blocks shall be laid in mortar made of one (1) part Portland Cement, one (1) part best Rockland lime and three (3) parts sand. The bed joints shall be buttered and the work shall be laid up with such care that mortar will not accumulate in the holes of the blocks. The Contractor shall keep the hollow spaces clean to the satisfaction of the Engineers. Joints shall not be over ⅜″ thick and shall be struck with a trowel.

Granite and Granite Masonry.—All pier caps, templates and pedestals, where so shown and required by drawings, shall be of cut granite.

Granite must be strong, sound, compact, moderately fine grained, of uniform quality and appearance, and free from any defect which in the judgment of the Engineers may impair its strength and durability.

The bottom bed shall always be of the full size of the stone and no stone shall have an overhanging top bed.

The stones shall be cut to the dimensions shown on drawings.

The face lines of each stone shall be true, and the rise as fixed by the face line shall not vary anywhere more than $\frac{1}{16}$ of an inch from the true rise shown on the drawings.

The upper and lower beds shall be truly parallel. The lower bed shall have no depression within six inches of the face and none exceeding one inch in depth nor more than six inches in its greatest dimension over the remainder of the bed. Depressions of more than

¼ in. below the true plane shall never exceed over ⅛ of the area for the bed.

Vertical joints shall be cut to exact lines on the upper bed face and for 6 inches back from the face of the lower bed. The remainder of the joint shall be cut to conform to the requirements for the lower bed.

The upper bed face and lower bed (of pedestals under girders) for a distance of six inches back of the face shall be bush-hammered, six-cut with true lines and surfaces.

The upper bed and the lower bed of pier caps and templates for a distance of six inches back from the faces shall be bush-hammered, six-cut with true lines and surfaces.

These pier caps and templates shall have rock faces. No grab hole or lewis hole shall be made in the bed or face of any stone.

Stones shall be set in full beds of mortar containing 1 volume of cement to 2½ volumes of sand. All stones must be carefully cleaned and wet before setting.

No stone shall be laid in freezing weather, except with the express permission of the Engineers, and under such conditions as they may impose to secure immunity from injury by freezing.

Joints shall be caulked temporarily with oakum or rope yarn and filled with a thin mortar of the same composition as used for beds well worked in with a sword so as to completely fill the joints.

All the joints shall be cleaned out to a depth of 1½ inches and pointed in mild weather with a mortar containing one volume of cement to two parts of sand, mixed with a small proportion of water and driven into the joint with a calking iron.

All granite masonry foundation walls shall be built of dimension stones laid on a full and sufficient bed of Portland cement mortar made in proportions of one volume of cement to 2½ volumes of sand.

All joints to be thoroughly filled with cement and carefully chinked with slate spalls.

All stones to be derrick laid and no joints to exceed two (2) inches in thickness.

All joints shall be thoroughly broken as shown on the drawings.

The measurements on all granite and granite masonry will be taken in cubic contents to the draft lines and no allowance made for rock face.

Vitrified Conduits for Electric Cables.—The vitrified conduits for electric cables shall be manufactured of the best clay, thoroughly burned, sound in all respects, straight and free from splits, fractures, soft spots, stones, cracks or blisters tending to impair their strength or durability. They shall be thoroughly and completely glazed with good salt glaze. The interior surfaces of the duct holes shall be smooth and free from any projections or imperfections which may tend to strip the lead coating from the electric cable when pulled through the duct. The ends shall be cut smooth and square with the axis. Ends of holes

shall be slightly bell-mouthed. When conduits are cut to special lengths, the cut end must be dressed with chisel and rasp until the hole is slightly bell-mouthed and has smooth edges.

Conduits shall be of whatever form and pattern the Engineers may require, either single or multiple duct conduits. In the four-way conduits, dowel holes are to be formed at each end for truly centering the sections when laying. The standard length of single-duct conduits shall be eighteen (18) inches and four-way conduits thirty (30) or thirty-six (36) inches, as the Engineers may determine from the samples submitted. The lengths must not vary from the standard by more than ¾ inch. The duct holes in single-duct conduits shall not be less than three and one-half (3½) inches nor more than three and seven-eighths (3⅞) inches in diameter, or square with corners rounded; the outside walls and webs shall be ¾ inch thick. The outside dimensions of four-way ducts shall not exceed nine and one-half inches on a side. The conduits shall be square on outer lines with corners rounded.

The adopted sample sections of conduits exhibited at the office of the Engineers shall represent in every way the conduits to be furnished by the Contractor.

The conduits shall be laid in about ¼ inch beds of mortar and in perfect alignment and grade throughout. The vertical joints between conduits shall be filled with mortar and the concrete carried up in layers as the conduits are laid. Dowels with central washer shall be provided by the Contractor and placed in every dowel hole. A wooden mandrel four (4) feet long, the center dimensions of which are ⅛ inch less than the bore of the conduits, the end dimensions of which are ½ inch less than the bore of the conduits, shall be threaded through each hole after the conduits have been bedded in place, and the Engineers may require the Contractor to thread the mandrel through a second time. A spring steel tube scraper with a flue brush behind it, or other device approved by the Engineers, shall be attached to the end of each mandrel and used to remove all foreign matter from the ducts. All ducts must be thoroughly cleaned to the satisfaction of the Engineers.

Butt joints of conduits shall be broken at every tier half the length of the section, or as may be specially required by the Engineers. Every joint of the four-way conduits shall be lapped around with two (2) thicknesses and six (6) inches overlap of No. 6 cotton duck canvas six (6) inches wide, three (3) inches on each abutting section, saturated with neat cement grout immediately before placing. These laps are to be doubled on curves. Single-duct conduits are to be lapped on curves only.

Short sections of conduits shall be used at manholes only to effect proper bond and closures. These short sections shall be cut cleanly and truly square across without splitting the ducts. No four-way conduit section shall be cut less than twelve (12) inches long, and no single conduit section shall be cut less than nine (9) inches long.

Paraffined wooden plugs shall be furnished by the Contractor and placed in the free ends of all ducts when work is discontinued and shall be left in place.

Electric conduits shall be measured in the work and the unit price shall include dowels, canvas lapping and paraffined plugs.

Manholes will be built at intervals and in accordance with plans furnished by the Engineers. Iron manhole castings and covers, doors and other details as shown on the plans shall be supplied and set in place by the Contractor.

One No. 8 B. and S. gauge galvanized iron wire shall be placed, pulled and left in each duct from manhole to manhole.

Conduits will be enveloped in waterproofing laid around the encasing concrete where shown on drawings, and in the manner hereinafter specified under "Waterproofing."

Wrought Iron Pipe for Electric Ducts.—Where iron pipes are required for electric ducts, they shall be standard wrought iron, lapwelded pipes, three and one-half ($3\frac{1}{2}$) inches diameter inside.

Bent pipes shall be free from distortion in cross-section, and the bends shall not vary anywhere more than one (1) inch from the form required.

The ends of pipes shall be smoothed and rounded with a file on the inner edges, so as not to injure the lead covering of the electric cables, when drawn through. Paraffined wooden plugs shall be furnished by the Contractor and placed in the free end of all ducts when work is discontinued and shall be left in place.

Waterproofing.—It is intended that the interior of water-proof structures shall be permanently free from moisture or discoloration due to the percolation of water or other liquids from outside sources. This end shall be attained by means of a continuous flexible water-proof sheet surrounding the exterior of the structures (as shown by drawings).

Pitch used shall be straight run coal-tar pitch, which shall soften at 60 degrees F. and melt at 100 degrees F.; being a grade in which distillate oils distilled therefrom shall have a specific gravity of 1.105.

The felt shall be "Hydrex" felt manufactured by F. W. Bird & Son, East Walpole, Mass., or felt equally satisfactory to the Engineers.

Pitch, when applied, shall be of a temperature of not less than two hundred fifty (250) degrees F. The pitch shall be mopped on the surface of the masonry to a uniform thickness of not less than $\frac{1}{16}$ inch. Each layer of pitch must completely cover the surface on which it is spread without cracks or blowholes. The felt must be rolled out into the pitch while the latter is still hot and pressed against it so as to insure its being completely stuck to the pitch over its entire surface. Great care must be taken that all joints in the felt are well broken, and that the ends of the rolls of the bottom layer are carried up on the inside of the layers on the sides, and those of the roof down on the out-

side of the layers on the sides, so as to secure the full laps herein specified.

Waterproofing must be protected against injury at all times to the satisfaction of the Engineers.

Any waterproofed structure that is found to leak at any time prior to the completion of this contract shall be made tight by the Contractor in a manner satisfactory to the Engineers.

Waterproofing shall consist of six (6) layers of felt and seven (7) layers of pitch alternating, each strip of felt to lap not less than one (1) foot upon the previously laid strip and each section of waterproof sheet shall lap at least one (1) foot with the adjoining section.

Waterproofing will be measured by the square of one hundred (100) superficial feet and paid for accordingly.

Erection of Steel.—All steel will be furnished by the Railroad Company, delivered at a North River dock situated between West 29th and West 39th Streets, inclusive, Borough of Manhattan, City of New York. The Contractor shall receive the steel so delivered and transport it to the site of the work.

Contractor shall erect all the structural steel shown on or required by drawings and paint the same the specified number of coats of paint, and shall set all anchor bolts and do all field riveting required. Before, or during erection, all material shall be laid on skids above the ground so as to be kept clean. It shall be handled so as to avoid injury to the material. Any piece showing the effects of rough handling shall be repaired or replaced by the Contractor at his own expense.

Contractor shall furnish all equipment necessary and shall furnish and build all false works required for the proper erection of the steel work.

All grillages shall be set, filled and encased in Portland Cement concrete and grout (prior to the erection of the superimposed steel work) to the exact lines and grades given by the Engineers. Grillages so set shall be maintained in true position by the Contractor, and no steel work shall be placed upon the same until the Engineers so direct.

The floor plate which rests on the plate girder bridging shall consist of rolled steel beams imbedded in concrete as shown on the drawings. The bottom layer of concrete shall be laid in place by the Contractor before the floor beams are erected. The beams may be of varying lengths, not less than twelve (12) nor more than thirty (30) feet long, and they shall be spaced as shown on the drawings, breaking joints every six (6) or eight (8) beams. All of these beams must be straight and clean when laid in place.

Rivets shall be $\frac{7}{8}$ of one inch in diameter unless otherwise shown on the drawings. They shall have full hemispherical heads and shall completely fill the holes and be true and perfect in every way. Any loose, burned or otherwise defective rivets discovered at any stage of the

work shall be cut out and replaced by the Contractor. Field rivets shall be driven by pneumatic riveters wherever possible.

Slight misfits incidental to all erection, requiring reaming of unfair holes, etc., shall not be considered extra work.

All of the steel work to be incased in concrete except columns, and except as hereinafter specified, shall not be painted. The Contractor shall remove all dirt or filth which may be found on the steel delivered to him prior to erecting the same, to the satisfaction of the Engineers. He shall also clean all steel work which may be otherwise damaged after delivery to him. After erection, all steel work except grillages, floor plate, and those portions of plate girders imbedded in concrete, shall receive three (3) good coats of graphite paint of colors to be selected by the Engineers, or one (1) coat of "Tockolith" and two coats of No. 49 R. I. W. paint; each coat to be allowed to dry before another coat is applied. These three (3) final coats shall be applied immediately before erecting the girders, to surfaces which will not be accessible after erection.

Graphite paint to be used on the work shall be Dixon's Silica Graphite Paint, manufactured by Joseph Dixon Crucible Company, Jersey City, N. J., or other graphite paint of equal quality and satisfactory to the Engineers.

"Tockolith" to be used on the work shall be the Portland Cement paint of that name manufactured by Toch Brothers of New York City.

R. I. W. paint shall be the paint of that name manufactured by Toch Brothers, New York City.

The vehicle of the above graphite paint shall be boiled linseed oil. No adulterated or thinner oils shall be used. The boiled linseed oil must be absolutely pure, containing no matters volatile at two hundred (200) degrees F. in a current of hydrogen; shall not contain any resin or manganese and shall be perfectly clear upon delivery, and on standing no deposit should form, providing the oil be kept at a temperature of forty-five (45) degrees F. The film left after flowing the oil over glass and allowing it to drain in a vertical position must be dry to the touch after twenty-four (24) hours.

No painting shall be done in wet or freezing weather and no paint shall be applied to damp surfaces, or surfaces which are not thoroughly clean or dry.

APPENDIX B.

Street Bridging Steel.

Proportion of Parts.—No material shall be used less than $\frac{3}{8}$ of an inch thick, except that lattice bars or sway bracing may be $\frac{5}{16}$ of an inch thick, and except as may be required for lining and filling.

The various parts of the structures (except the 9th Avenue viaduct) are proportioned to sustain the following unit strains given in pounds per square inch.

Tension = 17,000 lbs. (net section).

For determining the net sections, rivet holes are assumed to be of $\frac{1}{8}$ inch greater diameter than the cold rivet.

$$\text{Compression} = \frac{17{,}000 \text{ lbs.}}{1 + \dfrac{L^2}{11{,}000\, r^2}}$$

Wherein L is the length of the member in inches and r is the least radius of gyration in inches.

No combination of stresses shall exceed 17,000 lbs. per square inch.

Shear in webs of plate girders (gross section)..10,000 lbs.
Rivet bearing ....22,000 "
Shearing strain on rivets shall not exceed......11,000 "

For field connections the number of rivets thus found shall be increased 25 per cent. if driven by hand, but increased 10 per cent. if driven by power.

The various parts of the 9th Avenue viaduct are proportioned to sustain the above unit strains for all loads excepting the reactions at the base of the Elevated Railroad pillars for the support of which the parts of the viaduct affected thereby are proportioned to sustain the following unit strains given in pounds per square inch:

Tension = 9,000 lbs. (net section).

For determining the net sections, rivet holes are assumed to be of $\frac{1}{8}$ inch greater diameter than the cold rivet.

Compression = 9,000 lbs.

Reduced by Gordon's formula using a factor of safety 5.

Sheer in Webs of Plate Girders, 7,500 lbs.
Rivet Bearing = 15,000 lbs.
Shearing Strain on Rivets = 7,500 lbs.

For field connections the number of rivets thus found shall be increased 25%, if driven by hand, but increased 10%, if driven by power.

All girders shall have a sufficient number of end stiffeners to transmit vertical shear into the web, and all rivets in these end stiffen-

ers shall be counted upon to take this vertical shear. Intermediate stiffeners shall be used at points of superimposed concentrated loading. Rivet pitch for stiffeners shall not exceed $4\frac{1}{2}$ inches. Stiffeners shall be used on all girders, the webs of which are less in thickness than $\frac{1}{80}$ of their unsupported depth, also on all girders the webs of which sustain a greater load than is allowed by the following formula:

$$P = \frac{11{,}000}{1 + \dfrac{d^2}{3{,}000\, t^2}}$$

In which

P equals allowed strain per square inch of section,
d equals unsupported depth of web in inches,
t equals thickness of web in inches.

Intermediate stiffeners shall be spaced not more than 5 feet apart, usually at intervals equal to the depth of the girder, and as shown on detail drawings.

Girders which carry masonry arches shall be provided with shelf angles as required by drawings.

In calculating shearing strains and bearing strains on web rivets of plate girders the whole of the shear acting on the side of the panel next to the support is considered to be transferred into the flange angles in a distance equal to the depth of the girder.

Where cover plates are used, one cover plate must be of full length of girder on top flange where shown or noted.

Girder bearing plates are so proportioned that the pressure upon the bridge seat shall not exceed 400 pounds per square inch, except for the 31st Street and 33rd Street viaducts where they are proportioned for 250 pounds per square inch.

Base plates of columns are so proportioned that the pressure upon the cut granite cap stones shall not exceed 750 pounds per square inch.

The pitch of rivets shall not be less than three diameters of the rivet, not greater than four diameters of rivet in end panels and not greater than six inches in single rows or $4\frac{1}{2}$ inches alternating, in any case. At the end of columns the pitch shall not exceed four diameters of the rivet for a length equal to twice the width of the column.

The distance from the center of a rivet hole to the rolled edge of any piece must not be less that $1\frac{1}{2}$ times the diameter of the rivet and in no case less than $1\frac{1}{4}$ inches and not greater than 8 times the thickness of the thinnest plate.

Rivet grip shall not exceed five diameters of the rivet.

Countersunk rivets shall be assumed to have $\frac{3}{4}$ of the value of rivets having full heads.

The compression flanges of plate girders have been designed of same section as that determined for tension flanges.

Columns and girders shall not be spliced without the approval of the Engineers unless so shown on the drawings. The webs of plate girders must be spliced at all joints by a plate or plates on each side of the web.

Due account must be taken of the fact that the girders under and east of 7th Avenue have been so designed that $\frac{1}{8}$ of their web section is included in the area of the flange.

The abutting joints of columns which are spliced must be milled, and the splices must be symmetrical and be sufficient to maintain the parts accurately in contact and against tendency to displacement.

If it be required to splice flanges of girders, such splices must develop the full strength of the abutting sections.

Workmanship.—All riveted work shall be sub-punched and reamed $\frac{1}{16}$ of an inch larger than the diameter of the cold rivet, and when the pieces forming one built member are put together the holes must be truly opposite, and any burr due to reaming must be removed. Material more than $\frac{3}{4}$ of an inch thick shall be drilled.

All holes for field connections shall be accurately drilled to a template or reamed while the connecting parts are temporarily put together.

Rivets shall be $\frac{3}{4}$ and $\frac{7}{8}$ of one inch in diameter, as required by drawings. They shall have full hemispherical heads except where countersunk, and shall completely fill the holes and be true and perfect in every way.

Any loose, burnt or otherwise defective rivets discovered at any stage of the work shall be cut out and replaced by the Contractor.

All shop rivets shall be machine driven.

Countersunk rivet heads shall be chipped where required by the drawings.

All riveted work shall be straight, free from open joints, and present a neat appearance. Deformity will be cause for rejection.

All rolled shapes shall be straight and true to section. Deformity will be cause for rejection.

All stiffeners on girders shall be fitted to bear against top and bottom flanges, including fillers. All end stiffeners of girders must be in a true plane and square to the flange of the girder, unless otherwise shown.

Where sole plates are used on girders they must be bolted firmly to flange angles before end stiffeners are fitted.

The foot of all columns and the tops of columns where shown on or required by drawings shall be faced at right angles to the axis of the column. This facing shall be done after connecting knees, gussets and base angles or cap angles are riveted to the column, and the connecting parts shall be placed so carefully that after facing they shall have a perfect bearing.

Shoes and cap plates shall be perfectly straight.

Where noted on drawings girders which frame between columns (and all other girders similarly marked) shall be made of the exact length required by the drawings or their ends must be faced true and square.

Girder sole plates to be planed on bottom where required by drawings.

Bearing plates on masonry to be perfectly straight and true.

Tops of cast iron pedestals shall be planed true.

No material that has been damaged in handling will be accepted in any part of the work. All workmanship shall be first class in every respect and satisfactory to the Engineers.

Quality of Material.—Rolled Steel.—The steel is to be made by the open hearth process, and the finished product must be free from injurious defects and be straight and true to section, with smooth surface and clean edges.

All steel except that for rivets shall be medium steel.

If made by the acid process it shall not contain more than 0.08% phosphorus, and if made by the basic process not over 0.06% phosphorus.

Steel shall have an ultimate tensile strength of from 60 000 to 70 000 pounds per square inch; an elastic limit at least one-half of the ultimate strength, and a minimum elongation in 8 inches of 22%.

The elastic limit of the steel is to be determined by the drop of the beam or halt in the gauge of the testing machine.

Rivet steel shall not contain more than 0.04% phosphorus, not over 0.05% sulphur and not more than 0.05% manganese.

Rivet steel shall have an ultimate tensile strength of from 48 000 to 56 000 pounds per square inch, an elastic limit not less than 28 000 lbs. per square inch, a minimum elongation in 8 inches of 28%, with an average reduction in area of about 56%.

A variation in cross-section or weight of material of more than 2½% from that specified may be cause for rejection.

Certified ladle analysis will be required of all heats, free of charge. The Engineers may have check analysis made of drillings from the finished material, which shall determine the acceptance of the material. The limits of phosphorus so found shall not exceed the specified limits by more than 25%. Samples for chemical analysis to be taken from each heat and from drillings of the finished product.

Every finished plate, bar or shape shall be stamped with a number identifying the heat and plainly marked.

Tensile and bending tests shall be made on test pieces cut from the finished material representing each heat.

The test piece shall be a manufacturers' standard test piece of 8 inches gauged length, of full thickness of material under test.

Steel shall bend cold 180 degrees around a diameter equal to the thickness of the specimen tested without showing cracks on the outside of the bent portion.

Rivet steel shall bend cold 180 degrees flat on itself without showing cracks on the outside of the bent portion.

Rivets cut out from work in which they have been driven shall show a tough, silky structure with no crystalline appearance. Every steel plate, bar or shape must be capable of standing a drifting test by punching a ⅞-inch hole 1¼ inches from the edge and enlarging this hole to 1½ times its original diameter without cracking the metal.

The fracture of all steel must be silky and have no crystalline appearance.

The Contractor shall furnish free of charge prepared specimens for testing, the use of a testing machine satisfactory to the Engineers and all facilities and necessary assistance, for making the tests.

All material shall be new and free from rust when received at the shop and there protected against undue damage to shape or surface.

No material shall be assembled for punching and reaming before it has been inspected by the duly authorized shop inspector.

Paint shall not be applied to any surface until it has been inspected.

The Contractor for the steel work shall furnish facilities for inspection and testing of material and workmanship at any time during shop hours for the duly authorized representatives of the Engineers.

Cast Iron.—All castings shall be of tough, gray iron, free from injurious cold shuts or blow holes, true to pattern and of workmanlike finish. Test bars one inch square, loaded in middle between supports 12 inches apart, shall bear 2,500 pounds or over, and deflect 0.15 of an inch before rupture.

Painting.—As soon as the work is riveted in the shop and before being exposed to the weather, it shall be thoroughly cleaned and given a thorough coating of Graphite paint or "Tockolith."

This coating shall be worked into all joints and crevices.

Surfaces which are to be riveted together shall be painted before assembling with one good coat of above paint. Any parts which are to be riveted together in erection shall receive two coats of paint before leaving the shop.

All rolled shapes except those to be used in the concrete steel floor plates shall be painted as provided herein for riveted work.

All of the steel beams of the concrete steel floor plates which are to be imbedded in concrete shall be thoroughly cleaned and shipped without painting.

All the plate girders in the work east of 7th Avenue which are to be encased in concrete shall be thoroughly cleaned and painted with

one coat of "Tockolith," except that on their bottom flanges either Graphite paint or "Tockolith" shall be used as provided herein for all other steel work.

Graphite paint to be used on the work shall be Dixon's Silica Graphite Paint, manufactured by Joseph Dixon Crucible Company, Jersey City, N. J., or other graphite paint of equal quality and satisfactory to the Engineers.

"Tockolith" to be used on the work shall be the Portland Cement paint of that name known as "Marine Tockolith," manufactured by Toch Brothers of New York City.

The vehicle of the above graphite paint shall be boiled linseed oil. No adulterated or thinner oils shall be used. The boiled linseed oil must be absolutely pure, containing no matters volatile at Two hundred (200) degrees F. in a current of hydrogen; shall not contain any resin or manganese and shall be perfectly clear upon delivery, and on standing no deposit should form, providing the oil be kept at a temperature of forty-five (45) degrees F. The film left after flowing the oil over glass and allowing it to drain in a vertical position, must be dry to the touch after twenty-four (24) hours.

No painting shall be done in wet or freezing weather and no paint shall be applied to damp surfaces or surfaces which are not thoroughly clean or dry.

APPENDIX C.

Station Building Steel.

General Description.—These specifications relate to manufacture and delivery of material required for the steel frame of the New York Passenger Station Building for the New York Terminal.

This building is a structure of the "cage" construction type, founded on masonry piers at and below track level, approximately 40 feet below the average elevation of the curbs of the surrounding streets and avenues.

The sidewalk beams along Seventh and Eighth Avenues are included in this contract, but the sidewalk beams and other structures outside of the building under Thirty-first and Thirty-third Streets are not included in this contract. Provision must be made, however, for the attachment of the parts of the Thirty-first and Thirty-third Street bridges to the building structure.

Loads.—In determining the weight of the structures for the purpose of calculating strains the weight of masonry floors has been assumed at 140 pounds per cubic foot. The structure has been designed for the dead load plus the following live loads:

Table of Live Loads.—Mezzanine Floors.—Waiting Rooms and Concourse, 150 lbs. per square foot.

All other floors below street, 300 lbs. per square foot.

Street Floors.—The entire Street Floor, 150 lbs. per square foot.

Sidewalks, 300 lbs. per square foot.

Upper Floors.—Floors of kitchen and second story shops, 150 lbs. per square foot.

All other floors above street, 100 lbs. per square foot.

Roofs.—Roofs which pitch more than 20 degrees, 30 lbs. per square foot.

All other roofs, 50 lbs. per square foot.

Proportion of Parts.—The various parts of the structures are proportioned to sustain the following unit strains given in pounds per square inch:

Tension = 16,000 lbs. (net section).

Tension in Riveted Sections = 14,000 lbs. (net section).

For determining the net sections, rivet holes are assumed to be of $\frac{1}{8}$ inch greater diameter than the cold rivets.

$$\text{Compression} = 15{,}200 \text{ lbs.} - 58\frac{l}{r}.$$

Wherein l is the length of the member in inches and r is the least radius of gyration in inches.

No column or strut shall have a length greater than 120 times its least radius of gyration.

Shear in webs of plate girders (gross section).	9,000 lbs.
Rivet bearing	20,000 "
Shearing strain on shop rivets shall not exceed	10,000 "
Shearing strain on field rivets shall not exceed	8,000 "

All girders shall have a sufficient number of end stiffeners to transmit vertical shear into the web, and all rivets in these end stiffeners shall be counted upon to take this vertical shear. Intermediate stiffeners shall be used at points of superimposed concentrated loading. Rivet pitch for stiffeners shall not exceed $4\frac{1}{2}$ inches. Stiffeners shall be used on all girders, the webs of which are less in thickness than $\frac{1}{60}$ of their unsupported depth, also on all girders the webs of which sustain a greater load than is allowed by the following formula:

$$P = \frac{11,000}{1 + \frac{d^2}{3,000\, t^2}}$$

In which P equals allowed strain per square inch of section.
d equals unsupported depth of web in inches.
t equals thickness of web in inches.

Intermediate stiffeners shall be spaced at intervals not exceeding 120 times the thickness of the web, and in no case more than 5 ft., as shown on detail drawings.

Girders which carry masonry arches shall be provided with shelf angles as required by drawings.

In calculating shearing strains and bearing strains on web rivets of plate girders the whole of the shear acting on the side of the panel next to the support is considered to be transferred into the flange angles in a distance equal to the depth of the girder.

Where cover plates are used, one cover plate must be of full length of girder on top flange where shown or noted.

Bearing plates for beams and girders, which rest on masonry, are proportioned in accordance with the following table of bearing values on masonry:

Brick work in Portland cement mortar, 250 lbs. per sq. in.
Portland cement concrete, 208 lbs. per sq. in.

The pitch of rivets shall not be less than three diameters of the rivet, not greater than four diameters of rivet in end panels, and not greater than six inches in single rows or $4\frac{1}{2}$ inches alternating, in any case. At the end of columns the pitch shall not exceed four

diameters of the rivet for a length equal to twice the width of the columns.

The distance from the center of a rivet hole to the rolled edge of any piece must not be less than 1½ times the diameter of the rivet, and in no case less than 1¼ inches and not greater than eight times the thickness of the thinnest plate.

Rivet grip shall not exceed five diameters of rivet.

Countersunk rivets shall be assumed to have ¾ of the value of the rivets having full heads.

The compression flanges of plate girders have been designed of same section as that determined for tension flanges.

Columns and girders shall not be spliced without the approval of the Engineers unless so shown on the drawings. The webs of plate girders must be spliced at all joints by a plate or plates on each side of the web.

The abutting joints of columns which are spliced must be milled, and the splices must be symmetrical and be sufficient to maintain the parts accurately in contact and against tendency to displacement.

If it be required to splice flanges of girders, such splices must develop the full strength of the abutting sections.

Workmanship.—All riveted work shall be sub-punched and reamed $\frac{1}{16}$ of an inch larger than the diameter of the cold rivet, and when the pieces forming one built member are put together the holes must be truly opposite, and any burr due to reaming must be removed. Material more than ¾ of an inch thick shall be drilled.

All holes for field connections shall be accurately drilled to a template.

Rivets shall be ¾ and ⅞ of one inch in diameter, as required by drawings. They shall have full hemispherical heads except where countersunk, and shall completely fill the holes and be true and perfect in every way.

Any loose, burnt or otherwise defective rivets discovered at any stage of the work shall be cut out and replaced by the Contractor.

All shop rivets shall be machine driven.

Countersunk rivet heads shall be chipped where required by the drawings.

All riveted work shall be straight, free from open joints and present a neat appearance. Deformity will be cause for rejection.

All rolled shapes shall be straight and true to section. Deformity will be cause for rejection.

All stiffeners on girders shall be fitted to bear against top and bottom flanges, including fillers. All end stiffeners of girders must be in a true plane and square to the flange of the girder, unless otherwise shown.

Where sole plates are used on girders they must be bolted firmly to flange angles before end stiffeners are fitted.

The foot of all columns and the tops of columns where shown on or required by drawings shall be faced at right angles to the axis of the column. This facing shall be done after connecting knees, gussets and base angles or cap angles are riveted to the column, and the connecting parts shall be placed so carefully that after facing they shall have a perfect bearing.

Shoes and cap plates shall be perfectly straight.

Where noted on drawings, girders which frame between columns (and all other girders similarly marked) shall be made of the exact length required by the drawings or their ends must be faced true and square.

Girder sole plates to be planed on bottom, where required by drawings. Bearing plates on masonry to be perfectly straight and true.

Tops of cast iron pedestals shall be planed true.

No material that has been damaged in handling will be accepted in any part of the work. All workmanship shall be first class in every respect and satisfactory to the Engineers.

Quality of Material.—Rolled Steel.—The steel is to be made by the open hearth process, and the finished product must be free from injurious defects and be straight and true to section, with smooth surface and clean edges.

All steel except that for rivets shall be medium steel.

If made by the acid process it shall not contain more than 0.08% phosphorus, and if made by the basic process not over 0.06% phosphorus.

Steel shall have an ultimate tensile strength of from 60,000 to 70,000 pounds per square inch; an elastic limit at least one-half of the ultimate strength, and a minimum elongation in 8 inches of 22%.

The elastic limit of the steel is to be determined by the drop of the beam or halt in the gauge of the testing machine.

Rivet steel shall not contain more than 0.04% phosphorus, not over 0.05% sulphur and not more than 0.5% manganese.

Rivet steel shall have an ultimate tensile strength of from 48,000 to 56,000 pounds per square inch, an elastic limit not less than 28,000 pounds per square inch, a minimum elongation in 8 inches of 28%, with an average reduction in area of about 56%.

A variation in cross-section or weight of material of more than 2½% from that specified may be cause for rejection.

Certified ladle analysis will be required of all heats, free of charge. The Engineers may have check analysis made of drillings from the finished material, which shall determine the acceptance of the material. The limits of phosphorus so found shall not exceed the speci-

fied limits by more than 25%. Samples for chemical analysis to be taken from each heat and from drillings of the finished product.

Every finished plate, bar or shape shall be stamped with a number identifying the heat and plainly marked.

Tensile and bending tests shall be made on test pieces cut from the finished material representing each heat.

The test piece shall be a manufacturers' standard test piece of 8 inches gauged length, of full thickness of material under test.

Steel shall bend cold 180 degrees around a diameter equal to the thickness of the specimen tested without showing cracks on the outside of the bent portion.

Rivet steel shall bend cold 180 degrees flat on itself without showing cracks on the outside of the bent portion.

Rivets cut out from work in which they have been driven shall show a tough, silky structure with no crystalline appearance. Every steel plate, bar or shape must be capable of standing a drifting test by punching a $\frac{7}{8}$ inch hole $1\frac{1}{4}$ inches from the edge and enlarging this hole to $1\frac{1}{2}$ times its original diameter without cracking the metal.

The fracture of all steel must be silky and have no crystalline appearance.

The Contractor shall furnish free of charge prepared specimens for testing, the use of a testing machine satisfactory to the Engineers and all facilities and necessary assistance for making the tests.

All material shall be new and free from rust when received at the shop and there protected against undue damage to shape or surface.

No material shall be assembled for punching and reaming before it has been inspected by the duly authorized shop inspector.

Paint shall not be applied to any surface until it has been inspected.

The Contractor for the steel work shall furnish facilities for inspection and testing of material and workmanship at any time during shop hours for the duly authorized representatives of the Engineers.

Cast Iron.—All castings shall be of tough, gray iron, free from injurious cold shuts or blow holes, true to pattern and of workmanlike finish. The test bars one inch square, loaded in middle between supports 12 inches apart, shall bear 2,500 pounds or over, and deflect 0.15 of an inch before rupture.

Painting.—As soon as the work is riveted in the shop and before being exposed to the weather, it shall be thoroughly cleaned and given a thorough coating of paint.

This coating shall be worked into all joints and crevices.

Surfaces which are to be riveted together shall be painted before assembling with one good coat of paint. Any parts which are to be riveted together in erection shall receive two coats of paint before leaving the shop.

All rolled shapes shall be painted as provided herein for riveted work.

All paint for this work shall be made in accordance with the following specifications:

Pigment	15%	by weight.
Linseed Oil and Driers.....................	75%	" "
Mineral Oil not volatile at 212° Fahrenheit..	5%	" "
Volatile Material at or below 212° Fahrenheit	5%	" "

The pigment must consist of 55 per cent. lamp black and 45 per cent. white lead, a variation of not more than two per cent. either way in any of the constituents being allowed, and should the variation exceed the two per cent. above mentioned, the paint will be rejected.

It will be noted that the paint above specified is supposed to be ready for spreading when received, and it must be so well ground, and the materials used of such a kind, that it will spread well under fair usage in the hands of the painters. The japans must be of such a kind that the paint will dry over night, under average conditions of weather, so that it may be second coated without difficulty. The lamp black and white lead must be pure and of good quality, and free from admixtures of other materials.

A sample gallon of the paint must be furnished and approved before the paint is used on the work. Samples of not less than one pint will be taken at random by the duly authorized inspector from each of ten barrels and will be sent to Charles B. Dudley, Chemist, Altoona, Pa., in "Sample for Test" box and can accompanied by "Sample for Test" tag properly filled out, and paint must not be used until report of test is received. Care will be taken to secure a well mixed sample.

The boiled linseed oil must be absolutely pure, containing no matters volatile at two hundred (200) degrees F. in a current of hydrogen; shall not contain any resin or manganese and shall be perfectly clear upon delivery, and on standing no deposit should form, providing the oil be kept at a temperature of forty-five (45) degrees F. The film left after flowing the oil over glass and allowing to drain in a vertical position, must be dry to the touch after twenty-four (24) hours.

No painting shall be done in wet or freezing weather and no paint shall be applied to damp surfaces or surfaces which are not thoroughly clean and dry.

AMERICAN SOCIETY OF CIVIL ENGINEERS
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TRANSACTIONS

Paper No. 1165

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. STATION CONSTRUCTION, ROAD, TRACK, YARD EQUIPMENT, ELECTRIC TRACTION, AND LOCOMOTIVES.*

By George Gibbs, M. Am. Soc. C. E.

Introduction.

The purpose of this paper is to describe concisely the New York Tunnel Extension of The Pennsylvania Railroad, and to record the methods followed in the design and execution of the portion of the work entrusted to the writer's department.

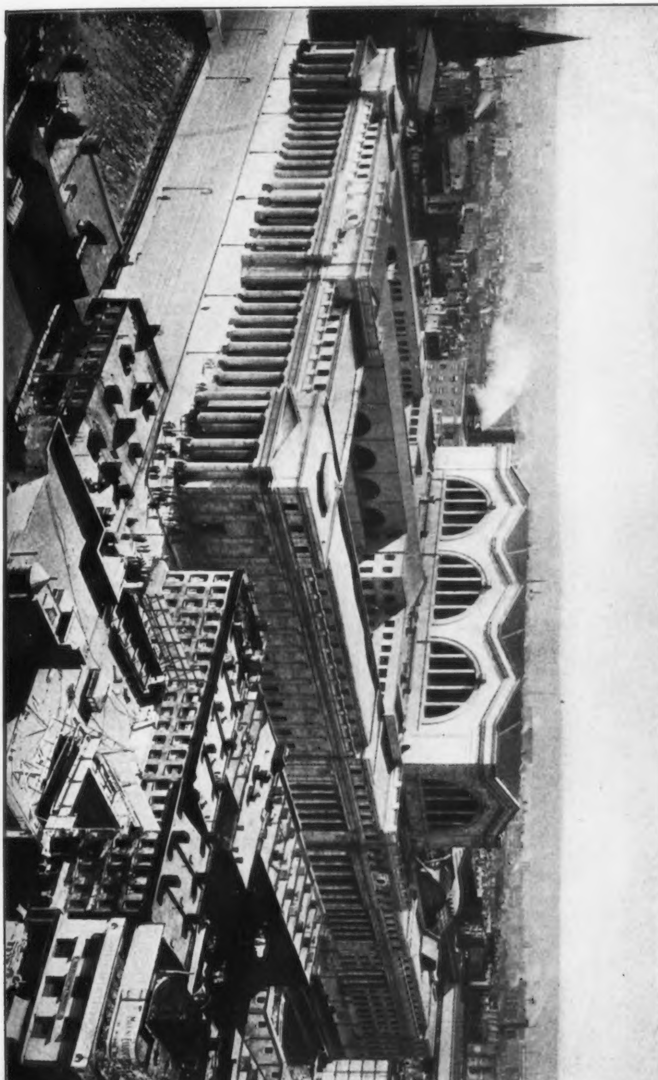
An outline of the entire terminal project is given in the paper† by Brig.-Gen. Charles W. Raymond, M. Am. Soc. C. E., Chairman of the Board of Engineers, in which it is shown that the construction was carried on under four general divisions, namely:

(1) The Meadows Division, under Alexander C. Shand, Chief Engineer, comprised the construction of an interchange yard near Newark, termed the "Manhattan Transfer," and a double-track railroad from the yard to Bergen Hill. The work of this division included the laying of all tracks ready for their equipment with signals and traction apparatus.

* Presented at the meeting of October 18th, 1911.

† *Transactions*, Am. Soc. C. E., Vol. LXVIII, p. 1.

PLATE LXXVI.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1165.
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.



BIRD'S-EYE VIEW OF STATION BUILDING FROM 33D STREET AND SEVENTH AVENUE.

(2) The North River Division, under Charles M. Jacobs, M. Am. Soc. C. E., Chief Engineer, comprised the driving of two tunnels under Bergen Hill and the North River to Tenth Avenue, Borough of Manhattan; also the excavation and retaining-wall work in that portion of the Terminal yard west of and under Ninth Avenue.

(3) The East River Division, under Alfred Noble, Past-President, Am. Soc. C. E., Chief Engineer, comprised the excavation of the main station yard to sub-grade; the building of marginal retaining walls from Ninth Avenue to the west side of Seventh Avenue; the construction of the cross-town tunnels under 32d and 33d Streets, beginning with the normal tunnel sections between Seventh and Sixth Avenues, and continuing as four separate tunnels to and under the East River and to the Long Island City portals; the construction of the approaches, and of Sunnyside Yard, including the grading and viaducts; also, in part, the main yard buildings.

(4) The Division of the writer, Chief Engineer of Electric Traction and Terminal Station Construction, comprised the design and construction of the structures and facilities hereinafter described.

Because of the great variety of subjects involved, it has been found necessary to treat each quite generally, referring only in some detail to special features, but leaving the complete description of any and all features for other engineers. For a full understanding of the project, as it relates to railroad operation, it has been necessary to repeat certain information given in other papers, but, as far as possible, the description has been confined to the work included in the writer's Division.

Terminal Railroad.

The New York Tunnel Extension, undertaken as a separate project, starts at a connection with the New York Division of the Pennsylvania Railroad, at Manhattan Transfer, one mile east of Newark, N. J. It includes a transfer yard at that point, a double-track elevated line across the Hackensack Meadows, two tunnels under Bergen Hill and the North River to the main Station yard centrally located on Manhattan Island, thence, as a four-track railroad, across the City and under the East River to and including a very large storage yard in Long Island City, and a connection with the Long Island Railroad in that yard. Table 1 contains the general data as to the location and physical characteristics of the railroad.

TABLE 1.—SECTIONS OF TUNNEL EXTENSION RAILROAD.

Section.	Termini of sections.	Character of line.	Length, in miles.	Main Running Tracks.			Total mileage of main and yard tracks.
				Number.	Maximum curve.	Maximum adverse grade.	
Manhattan Transfer.	5th Street, Harrison, to east end of bridge over N. Y. Div.	Passenger transfer and power interchange yard	1.57	4	3°15′	0.5%	17.79
Meadows	East end of bridge over N. Y. Div. to Bergen Hill Portal	Main line embankment	4.83	2	1°54′	0.3%	9.79
North River	Bergen Hill Portal to Tenth Avenue Portal	Land and river tunnel section	2.53	2	0°30′	1.93%	5.06
Station Yard	Tenth Avenue Portal to Standard Tunnel section near Sixth Avenue	Station yard	0.65	21	10°00′	0.4%	15.62
Cross-town Tunnels	Beginning of Standard Tunnel section near Sixth Avenue to First Avenue Shafts	Two twin tunnels	0.90	4	1°30′	1.50%	3.60
East River	First Avenue Shafts to Long Island City Portals	Four tube tunnels	1.48	4	1°30′	1.50%	5.90
Sunnyside	Long Island City Tunnel Portals to Laurel Hill Avenue	Storage and cleaning yard	1.45	8	2°42′	1.50%	36.81
			13.41				94.57

FIG. 1.—STATION YARD, LOOKING TOWARD NINTH AVENUE FROM THE WEST SIDE OF THE POST OFFICE.

FIG. 2.—STATION YARD, BETWEEN NINTH AND TENTH AVENUES, LOOKING WESTWARD.

The actual work of planning this railroad began in the early part of 1902, and continued until its completion, practically in all details, eight years thereafter. Regular Long Island Railroad train service was opened on September 8th, 1910, and the Pennsylvania Railroad service on November 27th, 1910.

The primary idea of the Terminal Railroad was to provide an all-rail line to a centrally located station in New York City, replacing the existing terminal in Jersey City, which was reached from New York only by ferries. Incidentally, it was to include a number of allied improvements intimately related to the Tunnel Extension project and with a direct bearing on its design. These were:

1st.—Improvements on the Long Island Railroad, a controlled property, by which its main terminal would be shifted from Long Island City to the New York Station, and would include an entire reconstruction of its main line to Jamaica, with four-tracking, electrification, and the elimination of grade crossings.

2d.—To open the residential sections of Long Island to the population of the thickly settled Borough of Manhattan, and to offer to Newark (a city of 347 000 inhabitants) and other populous towns in New Jersey direct and quick access to the resorts on the ocean beaches.

3d.—A direct rail connection *via* the Long Island Railroad to the West and South from the heart of Brooklyn and Queens Boroughs of New York City, containing 1 900 000 people, growing rapidly, and with ample area to accommodate a very large population.

4th.—The project (not yet carried into execution) of an all-rail connection for the New England States, through New York City, to the South and West for passenger service. This will be accomplished by building the "New York Connecting Railway" from Sunnyside Yard, on the New York Terminal Railroad, to Port Morris, on the New York, New Haven and Hartford Railroad, bridging the East River at Hell Gate.

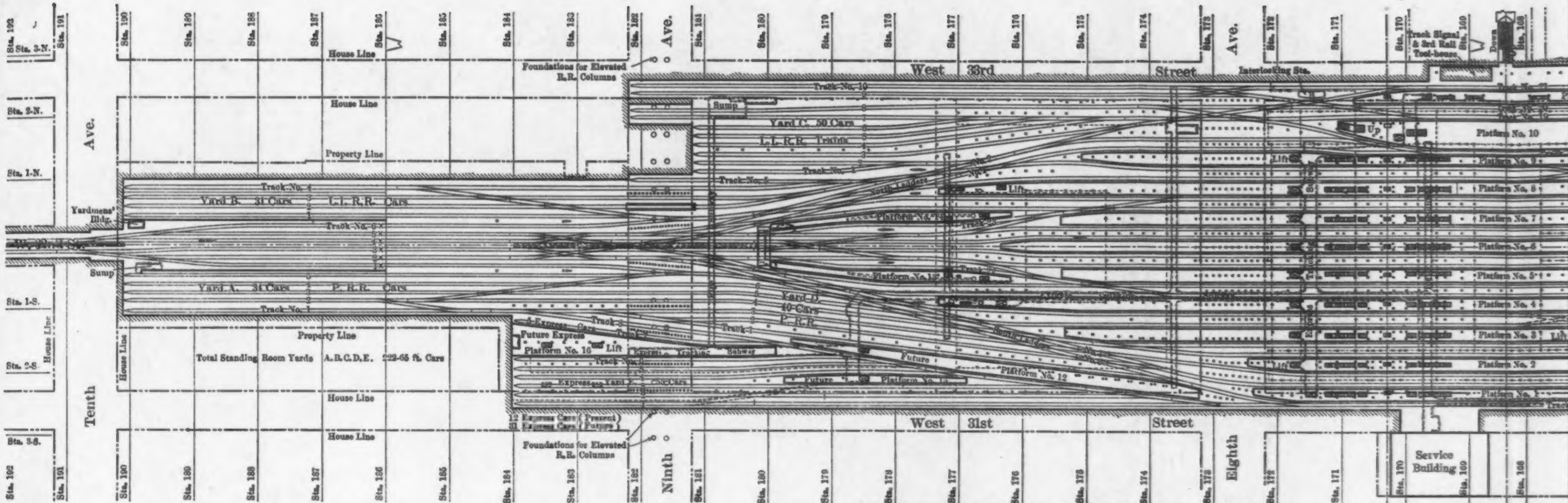
5th.—A down-town passenger terminal in the City of New York, secured by the electrification of the present New York Division tracks from Newark to Jersey City, and at that point connecting with the Hudson and Manhattan Railroad Company's line *via* tunnels under the North River to Church and Cortlandt Streets, New York City.

From the map* it is seen that the Station of this new railroad is centrally located, close to Broadway, the main city artery, and will serve the combined interests of business and residence on Manhattan Island. The district south of Central Park (59th Street) is being rapidly given over to business, amusements, and transient dwelling, and is the center for the moving throngs who require a transportation service. The Station is also central between the down-town business and the up-town residence districts.

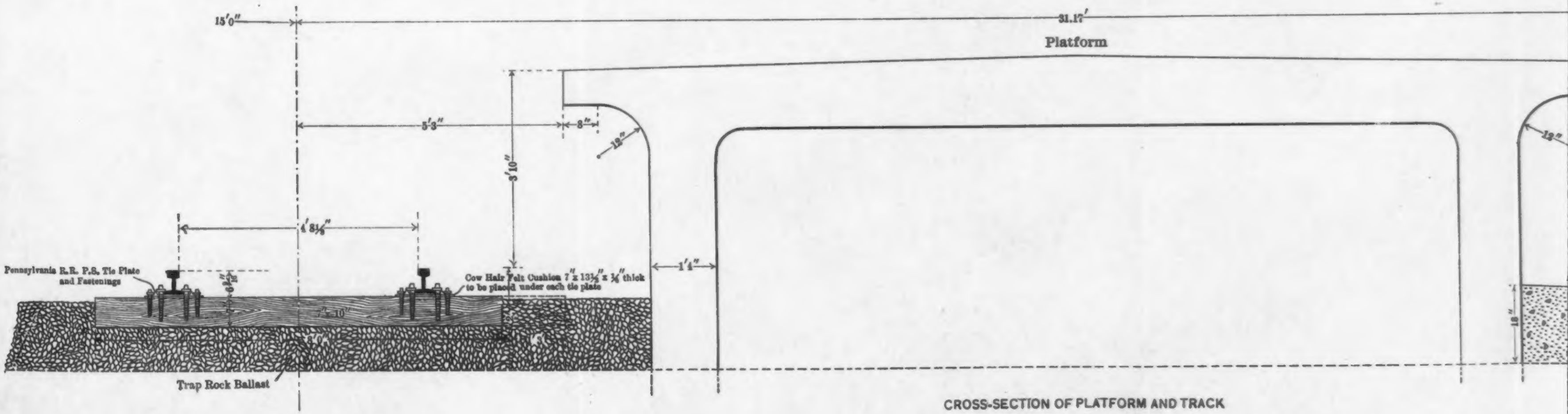
Time Saving.—The increase in convenience and the actual time saving secured to the traveling public, by the relocation of the main terminal of the great railway system which undertook this improvement, deserve recognition. Prior to undertaking the comprehensive scheme of rearrangement of and additions to its New York terminals, the Pennsylvania Railroad Company's station was at Jersey City, separated from the actual destination of its passengers by a wide river. The inconvenience of this arrangement was lessened as far as practicable by establishing a number of ferry lines to various points, along the water-front of Manhattan Island and to Brooklyn, between which fast and well-appointed boats were run at frequent intervals; but, at the best, transhipment from the trains to the city, across the river, consumed from 15 to 20 min. in good weather and about twice as much when foggy. From the marginal street along the river to the business or hotel districts, meant a further time of from 10 to 30 min., by walking or by car, through crowded city streets. Passengers to Brooklyn were obliged to make either a long ferry trip around the lower end of Manhattan Island, or a journey across two rivers and the city, with at least four transfers of conveyance, and the consequent loss of time, and inconvenience in arranging for baggage connections.

The Long Island Railroad had its main terminal in Long Island City, 10 min. by ferry to the 34th Street water-front, and 30 min. by ferry to the down-town district. Its Brooklyn terminal, at Flatbush and Atlantic Avenues, was reached by a steam railroad on the surface of a city street and subject to the delay and danger of operation under such circumstances; thence the traveler was carried into the down-town business portion of New York by surface or elevated car lines, *via* Brooklyn Bridge, and later by the subway.

* *Transactions*, Am. Soc. C. E., Vol. LXVIII, Fig. 1, p. 5.

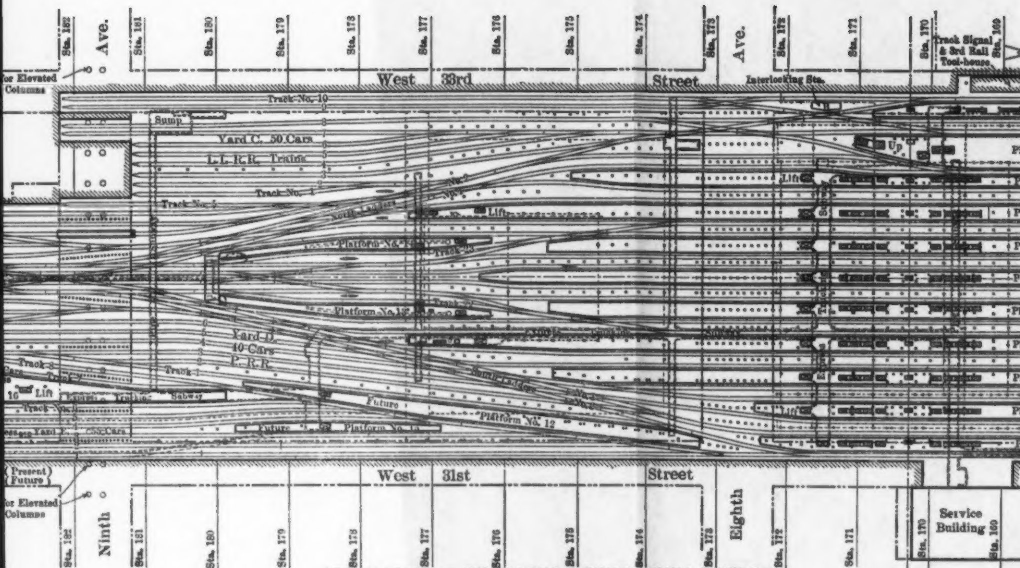


ARRANGEMENT OF TRACKS, PENNSYLVANIA STATION

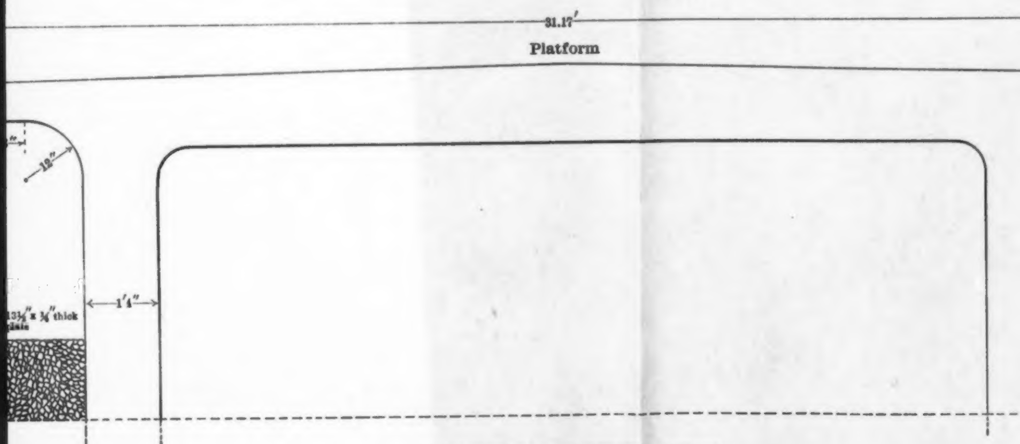


CROSS-SECTION OF PLATFORM AND TRACK

STATION YARD

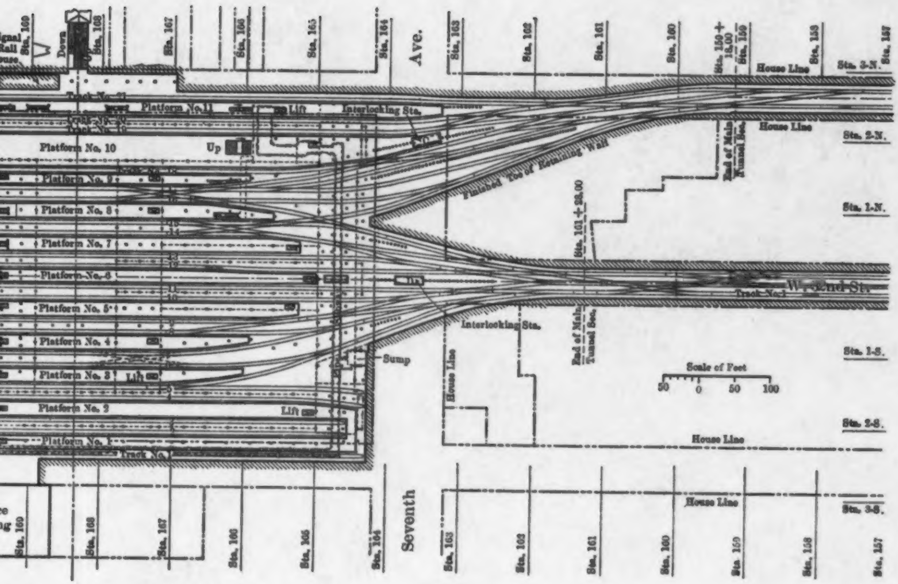


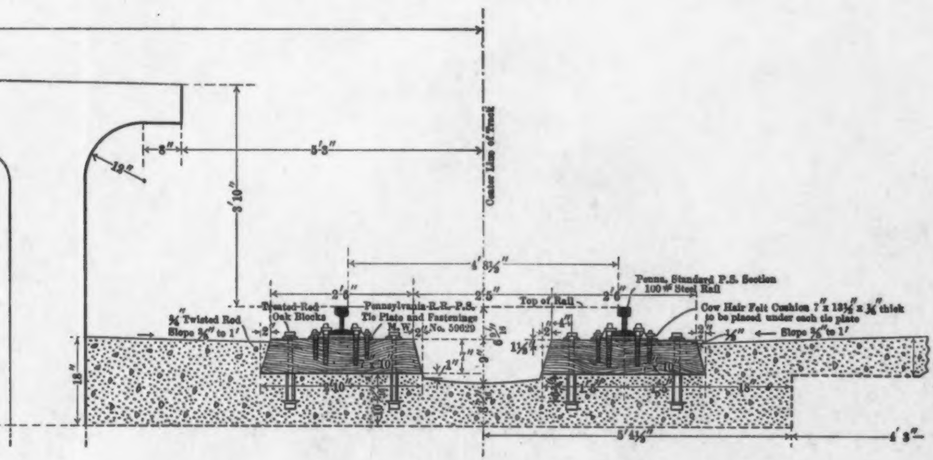
ARRANGEMENT OF TRACKS, PENNSYLVANIA STATION



CROSS-SECTION OF PLATFORM AND TRACK

STATION YARD


Seventh Ave.
W. 32nd St.
Platform No. 10
Platform No. 9
Platform No. 8
Platform No. 7
Platform No. 6
Platform No. 5
Platform No. 4
Platform No. 3
Platform No. 2
Platform No. 1
Platform No. 11
Interlocking Sta.
House Line
End of Main Tunnel Sec.
Sump
Lift
Up
Down
Scale of Feet
50 0 50 100
Sta. 3-N.
Sta. 2-N.
Sta. 1-N.
Sta. 1-S.
Sta. 2-S.
Sta. 3-S.
Sta. 168
Sta. 167
Sta. 166
Sta. 165
Sta. 164
Sta. 163
Sta. 162
Sta. 161
Sta. 160
Sta. 159
Sta. 158
Sta. 157


Center Line of Track
5'3"
8"
3'10"
4' 8½"
2'6"
2'5"
Top of Rail
Penna. Standard P.S. Section 100# Steel Rail
Treated Red Oak Blocks
Pennsylvania R.R. P.S. Tie Plate and Fastenings M.W. No. 50629
Cow Hair Felt Cushion 7" x 13½" x ¼" thick to be placed under each tie plate
¾ Twisted Rod
Slope ⅜" to 1'
18"
5'4½"
4'3"

Under the new conditions, briefly alluded to in this introduction, the main terminal of the Pennsylvania Railroad, used also by the Long Island Railroad, is in the heart of the greater City of New York, and is reached both from the east and west by modern electric railway lines, free from grade crossings, and suitable for high speed and frequent service. The down-town business district is reached from the west by rapid-transit service from the transfer station near Newark, and from the east by direct subway connection at Flatbush Avenue.

The time saving and convenience secured to the public by these improvements are evident. Under the new train schedules, Pennsylvania trains arrive at the New York Station in the time they formerly consumed in reaching Jersey City and lower New York, and Long Island trains in shorter time than that taken to reach Long Island City. In other words, passengers on either railway destined to the center of New York City, say Broadway and 34th Street, now save 30 min. over that required, under the best conditions, by former methods of transportation.

The collection of statistics, on which to base the required capacity of tunnels and station, was early begun by committees of the operating officers of the Pennsylvania Railroad, who formulated reports and made recommendations to the President, fixing the general characteristics of the entire project on a well-balanced plan, in which the present travel and anticipated growth for years in the future could be cared for without undue congestion of any feature.

The maximum capacity of the tunnels was based on the adopted speed and the spacing of the signals controlling train movements. In the case of the Station yard, the tracks were laid out to accommodate the maximum tunnel capacity (including tunnels to be built in the future), and tracks were assigned to each separate movement of a determined character; the switching work, time at platforms, and turn-around movements were all calculated, and working schedules were made. From the above followed a determination of the size and character of the Station Building.

A certain plan for the operating methods, assumed by the committee in fixing the station capacity, led to the following assignments of trains. This plan, of course, is subject to modifications as the classes of trains vary in the development of the service; thus, the

following is on the assumption that all Pennsylvania trains are handled by electric locomotives; if in the future, however, multiple-unit trains should be substituted for local service to New Jersey points, the station capacity would be greatly increased, as much shifting and transfer to Sunnyside Yard would be avoided:

Approach tracks from the west...........	2	
" " " " east	4	
Speed of trains, 50 to 60 miles per hour.		
Train interval under clear signal..........	2¼	min.
Capacity of each tunnel, per hour..........	26	trains.
Maximum capacity of all tunnels, per hour..	156	"

Station Movements:	Loaded trains, per hour.	Empty drafts, per hour.
Pennsylvania Railroad, on five tracks......	14	15
Long Island Railroad, " " "	19	16
" " " suburban, on four tracks	54	0
" " " head switching......	24	0
Pennsylvania Railroad, station turn-around.	10	0
" " Sunnyside Yard drafts.	0	31
Total capacity.....................	121	62

Time Allowance for Trains:

Standing at platforms, through trains:	
Inbound	7 to 8 min.
Outbound	15 " 20 "
Station turn-around:	
Local trains (tail switching)	
Minimum time to unload train........	1 min. 45 sec.
" " " load "	2 "
" " between departure of train and next arrival on same track.	1 " 20 "
Maximum daily capacity of station, based on maximum hourly capacity.......	1 160 trains.

General Information.—Other general statistics of the Terminal Railroad are as follows:

Length of run, Manhattan Transfer to Pennsylvania Station........................	8.78 miles.
Schedule time, Manhattan Transfer to Pennsylvania Station	13 min.
Length of run, Jamaica to Pennsylvania Station	11.8 miles.

FIG. 1.—STATION YARD: LOOKING EASTWARD FROM NINTH AVENUE.

FIG. 2.—HACKENSACK PORTAL OF NORTH RIVER TUNNELS.

Schedule time, Jamaica to Pennsylvania Station	18.0 min.
Total length of Tunnel Extension Railway, Manhattan Transfer to Laurel Hill Avenue, Long Island	13.41 miles.
Total length of single-track tunnels	14.57 "
Length of Bergen Hill Tunnel section	6 050 ft.
Length of river section, North River Tunnels	6 360 "
Length of land section, North River Tunnels	982 "
Length of cross-town section, near Sixth Avenue to East River (average)	4 747 "
Length of river section, East River Tunnels	3 949 "
Length of land section, Long Island City	3 847 "
Total distance, Hackensack tunnel portal to Long Island City tunnel portals (average)	5.58 miles.
Sunnyside Yard:	
3d Street to Laurel Hill Avenue	8 815 ft.
Extreme width	1 625 "
Area	192 acres.
Length of yard tracks (present)	25.72 miles.
Length of yard tracks (ultimate)	45.47 "
Manhattan Transfer Yard:	
Length	4 050 ft.
Width	250 "
Area	23 acres.
Length of yard tracks	11.49 miles.
Station Yard:	
Length, Tenth Avenue to Sixth Avenue	3 488 ft.
Width, net, at track level (31st to 33d Streets)	509 "
Area	28.3 acres.
Length of tracks	15.62 miles.
Pennsylvania Station:	
Length, east and west	789 ft.
Length, north and south	430 "
Area (of building at street level)	7.5 acres.
Total trackage of Terminal Railroad, present	94.57 miles.
Total main-line trackage	44.0 "
Initial daily train service, P. R. R. trains, in and out	150
Initial daily train service, L. I. R. R. trains, in and out	200
Summer schedule, 1911, P. R. R. service, in and out	200

Summer schedule, 1911, L. I. R. R. service, in and out	250
Number of electric locomotives for 1911 service	33
Number of buildings required for all purposes.	64
One traction power-house, capacity	40 000 kw.
Four traction sub-stations, total capacity	24 000 "
One service power-house, initial boiler capacity.	2 625 h.p.
Total weight of structural steel used for entire Terminal Railroad construction	80 350 tons.
Approximate total quantity of cement used for entire Terminal Railroad construction	1 942 000 bbl.
Excavation, including that for tunnels	6 936 673 cu. yd.

Station Yard.

The main yard serving the Pennsylvania Station Building is between Seventh and Tenth Avenues, and 31st and 33d Streets, including the sub-surfaces of these avenues and streets, and the surface as well as the sub-surface of 32d Street from Seventh to Tenth Avenues. Two views of the yard are shown on Plate LXXVII. It is rectangular in shape, with an irregular extension west of Ninth Avenue, and covers a net area of about 27 acres. It was excavated throughout to a depth of from 40 to 50 ft. below the original surface. The engineering considerations and the work involved in clearing buildings from the site, the excavation to sub-grade, and building the marginal retaining walls have been described by members of the staffs of the Chief Engineers of the North and East River Divisions having charge of this work.

The writer's Division was charged with the design and construction of the railway, the buildings and facilities, the permanent viaducts for supporting the streets over and around the yard, the restoration of the street surfaces, and the excavation and completion of the fan-shaped approaches to the tunnels at Seventh Avenue and eastward to the normal tunnel sections in 32d and 33d Streets. The engineering features of the viaducts and sub-surface work are fully described in the paper by George B. Francis and J. H. O'Brien, Members, Am. Soc. C. E.

The two easterly blocks, including the bed of 32d Street, are occupied by the main Station Building. West of Eighth Avenue, a plot 400 by 400 ft. has been sold to the United States Government for a general Post Office Building, now in process of erection. Easement for railway purposes has been reserved under this area, below a plane

FIG. 1.—SYSTEM OF REINFORCEMENT FOR TRUCKING SUBWAYS UNDER POST OFFICE; SIDE-WALL REMOVED FOR ENLARGEMENT OF SUBWAY.

FIG. 2.—STATION YARD, FROM 31ST STREET AND NINTH AVENUE, DURING TIME OF TRACK LAYING.

20 ft. above the tracks, subject to the reservation for the necessary supporting columns for the building, in locations fixed in the deed. West of the Post Office the area to Tenth Avenue is an open yard, bridged only by the viaducts over the side streets and Ninth Avenue. This open area may eventually be covered by marginal buildings. A plot 130 by 180 ft. has been reserved west of Ninth Avenue and at the north side of 31st Street for an Express Building, should it be desired at a later date to make the terminal a distributing point for express matter.

The sub-surfaces of Seventh, Eighth, and Ninth Avenues, and of 31st and 33d Streets, are in part occupied by the yard and in part by the retaining walls. It is of interest to state that everywhere in the yard the top of the track rails is from 9 to 23 ft. below mean high water in the harbor.

Track Plan.—The track plan is shown on the upper part of Plate LXXVIII. The summit of the yard is 530 ft. west of Seventh Avenue, from which point the grade falls east and west to the tunnel portals. From Tenth Avenue the grade rises eastward at the rate of 1.923% to a point midway between Tenth and Ninth Avenues, thence at the rate of 0.4% to the summit, and falls at the same rate to the Cross-town Tunnels. The track plan adopted was the result of extended study by the Terminal Committees of the Pennsylvania Railroad, and involved the making of about twenty tentative schemes in order to harmonize the operating requirements with the progressive development of the Station and Post Office Building plans. The primary aim was to balance the yard and tunnel capacity at the same maximum, having in mind the expectation that the yard should be capable of accommodating in the future the traffic from two more tunnels under the North River, making four in all, and two more under the East River, making a total of six. In doing this, certain assumptions were necessarily made as to the character of the traffic, that is, the amount of business handled by multiple-unit trains and those requiring electric locomotives, also the character of the switching operations to be done in the yard, and the amount of car storage needed.

The main approach tracks from the west fan out from the tunnel portals at Tenth Avenue into six running tracks, three for each direction, to the main switch leads at Ninth Avenue, thence by double ladders, one to the north and one to the south, into twenty-one plat-

form tracks covering the full width of the yard. Fig. 1, Plate LXXIX, is a view of the yard from Ninth Avenue, looking eastward. At the east end all except five of these tracks are again gathered into two groups, one leading to the two tunnel tracks under 33d Street, and one to the two tracks under 32d Street. At the extreme southeast, five stub tracks end at Seventh Avenue, to lead in future to two tunnels under 31st Street. It has been the aim to provide double leads throughout, as far as possible, so that simultaneous parallel movements can be made in reaching the various tracks connected therewith.

The station yard is not intended to provide unlimited car storage, but, nevertheless, considerable space for this purpose is available in the corners formed by the rectangular configuration of the lot and the rectangular extension west of Ninth Avenue, as shown by Table 2.

TABLE 2.—STATISTICS, STATION YARD.

PLATFORM FACILITIES AND CAR STORAGE TRACK ROOM.		
Number of station tracks adjoining platforms		21
Length of platforms adjacent to passenger tracks		21 500 ft.
Total area of platforms		244 270 sq. ft.
Number of passenger platforms		11
" " mail "		2
" " express " (future)		4
Four passenger platforms, average	21 ft. wide	900 ft. long.
" " " "	21 ft. "	1 050 ft. "
Two " " "	16 ft. "	1 000 ft. "
One " " " (L. I., loading)	47 ft. "	745 ft. "
Two mail " "		375 ft. "
Longest platform (No. 6)		1 140 ft. "
Total length of future express platforms		1 600 ft.
Mail cars standing at tracks adjacent to platforms		25 cars.
Storage space in yard "A" (Pennsylvania turning yard)		34 "
" " " " "B" (Long Island express yard)		31 "
" " " " "C" (" " local ")		50 "
" " " " "D" (Pennsylvania turning yard)		40 "
Total yard storage capacity		181 "
GENERAL STATISTICS OF THE STATION YARD AND FACILITIES.		
Total excavation (place measurement) for the entire yard, all contracts included		2 200 000 cu. yd.
Excavation begun (Mr. Noble's contracts)		July, 1904.
Viaduct erection started		Oct., 1905.
Viaducts completed		Jan., 1910.
Number of viaduct columns		771
" " Station Building columns		650
" " Post Office Building columns		200
" " columns for other structures		16
Total length of viaducts		5 985 ft.
Weight of structural steel in viaducts		23 500 tons.

The parallel tracks are generally spaced at 31-ft. centers, where platforms are between, and at 15-ft. centers otherwise, to allow for the placing of building column supports. The total length of tracks in the station yard is about 16 miles, of which 3 miles are adjacent to platforms.

MAIN WAITING ROOM.

Clearances.—The minimum overhead clearance in the yard between top of rail and girders is 16 ft. 2 in., the same as the clearance in the tunnels. The maximum car equipment height is 14 ft. 9 in. over all, and 15 ft. over all for locomotives, leaving a net minimum clearance of 1 ft. 2 in. between equipment and permanent overhead structures. The overhead contact rail has a clearance of 15 ft. 4 in. from the under contact surface to the top of the track rail.

The minimum clearance between sides of cars and columns between tracks is 1 ft. 6 in., whether the cars are on tangents or curves, and the minimum clearance for trucking on platforms is 5 ft., although in a few special instances it has been necessary to reduce this slightly. The clearance between the edges of the high platforms and the sides of the cars is 4 in.

Subways.—In the terminal yard area between Seventh and Ninth Avenues a comprehensive system of subways has been constructed under the tracks. They were deemed essential for the following purposes:

1st.—For housing the various piping systems to the buildings and tracks. These systems comprise very long runs, many of the pipes being of large diameter, to convey steam, air, and water, and have numerous connections to the buildings and at the track level. Proper and convenient maintenance required that all pipes should be readily accessible, which result could not be had by laying them in the ballast above the sub-grade; furthermore, because of the close spacing of the tracks, and the fact that this interspace is in many places occupied by columns, there was really no opportunity to lay out a practical pipe system in the ballast, and the buildings above the tracks were without basements in which to construct such a system.

2d.—The high station platforms (shown on the lower part of Plate LXXVIII), and the arrangement of the building itself, required provision for trucking baggage, mail, and express matter from one platform to the others, and this could be accomplished best by cross-trucking subways under the tracks. In places this was the only method possible, as some of the platforms are under the streets, and the baggage-rooms can be reached only by underground means.

3d.—Communication between the various important buildings, such as the Station, the Post Office, and the Express Building, could not be conveniently had at the track level or above, and therefore longitudinal trucking subways between them were necessary.

4th.—In the portion of the yard under and west of the most important signal cabin ("A"), at the intersection of the main-track ladder system, accessible space was required for the large quantity of signal apparatus, such as wiring, transformers, relays, and batteries. This space was provided by constructing a basement for the building, below the tracks, and a longitudinal subway for the conduits and instruments; from this subway all connections were conveniently made to the switches, and all apparatus was placed within easy reach.

The subways, therefore, while expensive to construct, furnish a valuable and comprehensive means of intercommunication for many important facilities, without interfering in any way with the scheme of tracks or train operation, or requiring important modifications in the buildings themselves.

As will be seen from the track plan, the subways include a main longitudinal system, from Seventh to Ninth Avenues, used in part for pipeways, in part for trucking purposes, and generally for both. This longitudinal system is intersected by cross-galleries consisting of baggage-trucking subways at each end of the Long Island platforms at the north side of the yard, a main cross-trucking subway immediately under the outgoing baggage-room in the Station Building and communicating with all lifts, and four cross pipe subways approximately 400 ft. apart, to cover the entire yard.

By the above, therefore, all platforms have intercommunication through the subways and by the lifts; the Station Building has access to the Post Office by a subway and lift reaching the operating floors of the latter building, and the same facilities will be furnished for the Express Building when erected. The building of these subways, as well as other sub-surface structures in the yard, such as under-drainage, building foundations, and conduits for power and telephones, was included in an important contract, the execution of which is recited in the paper by Messrs. Francis and O'Brien. Fig. 1, Plate LXXX, is a view under the Post Office, showing the system of reinforcement for the trucking subways; Fig. 2, Plate LXXX, is a view of the Station yard from 31st Street and Ninth Avenue, during the time of track laying.

Wall Around Yard.—The open area of the yard, to the west side of Ninth Avenue, has been permanently fenced by the construction of

MAIN WAITING-ROOM, LOOKING TOWARD ARCADE.

a marginal wall at the street level. This wall is carried on the street viaduct structure, is 6 ft. 5 in. high at the sidewalk side, and has a total length of 1 440 ft., enclosing Ninth Avenue, 31st and 33d Streets. The body of the wall is of a special gray mottled brick (in color closely resembling granite), with a base course and coping of granite. There are pilasters at intervals of about 40 ft. and paneled brickwork between.

Station Building.

The plan and engineering features of this great building, designated "Pennsylvania Station," deserve more extended description than can be given in a general paper covering so many subjects. In size, the building is unprecedented among railway stations, having a ground area of 7½ acres, about twice that of St. Peter's, in Rome, and 30% more than the area of the Palais de Justice, in Brussels (the latter being considered the largest building of the 19th century), and two and one-half times that of the New York Public Library. In length, the Station, east and west, is somewhat greater than that of the Capitol at Washington. In contents, it measures about 40 000 000 cu. ft. In plan, it is intended wholly for railway purposes and the comfort and convenience of passengers, and its design has not been subordinated to the purposes of a hotel or office building. In consonance with its legitimate purpose, however, the aim has been to make the structure a monumental gateway to the largest city in the country.

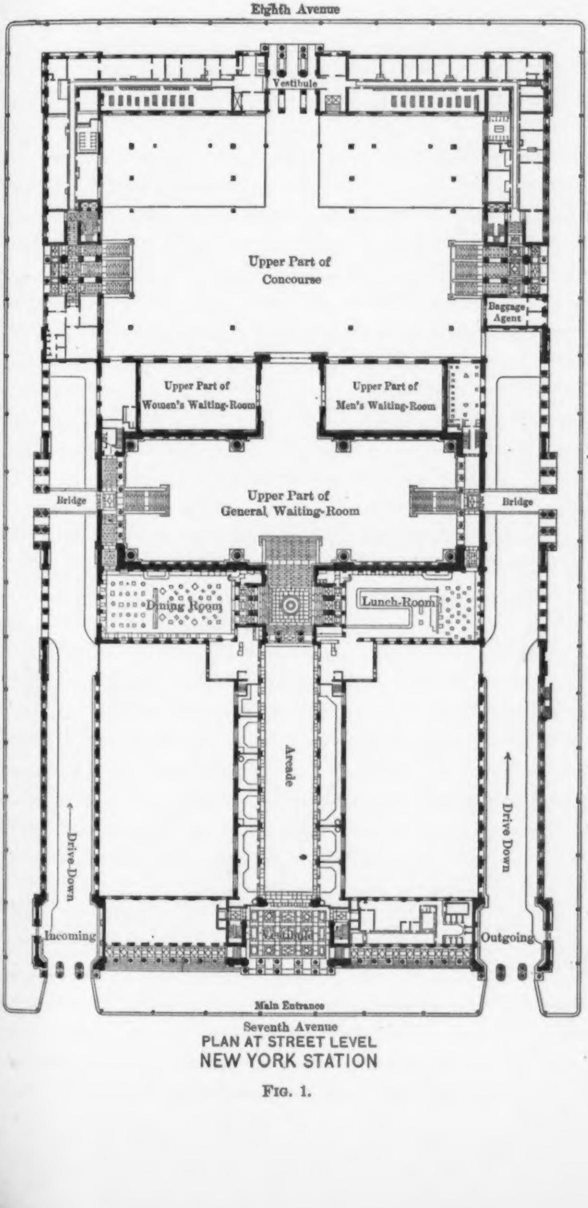
General Plan.—A passenger terminal may be located either adjoining or over the tracks served. The former plan has been generally adopted heretofore, where land was cheap, and especially because of the necessity of large open spaces in order to dispose of the smoke and steam from locomotives. In very large modern terminals, however, this plan has disadvantages in the costly property involved and in the enormous distances between the head-house facilities and the point where the passengers board the trains. Furthermore, with the advent of trains propelled by electric motors, it is entirely possible to utilize the basement of a station building for the tracks, and the levels immediately above for the facilities. Thus, when passengers arrive at the station, they are at the nearest point to the one where they embark on the train. It is true that this arrangement involves different levels, and thus the use of stairs or lifts, but, in order that a station may be in the heart of a great modern city, the depression or elevation

of the tracks is unavoidable, and stairs are a necessity, regardless of the location of the building.

The form of construction adopted for the Pennsylvania Station, therefore, is that of a bridge over the yard and platforms, the building having its main floor intermediate in level between the streets and the track platforms. The main station facilities are centrally located as regards the building itself, which may be entered from any one of its four sides, and also as regards the trains at the platforms underneath, so that the distances, which are necessarily considerable in a station of large capacity, are the least possible. It is believed that the unusual opportunities afforded for entrance and exit at the centers of the four sides, and the separation of incoming and outgoing passengers on different levels, make this building unique among the large stations of the world in the distribution of crowds without delay or confusion. These numerous means of access, moreover, should prove an important factor in building up the section of the city surrounding it, not only from one but from all sides.

Because of the location of the passenger facilities on different levels, it is difficult to show clearly by plans and cross-sections the arrangement of the building, nor can a clear description be concisely given. In general, however, the station consists of a hollow rectangle of marginal buildings surrounding the plot from the street level upward, as shown by Fig. 1; an intermediate building at the street level, starting from the middle of the Seventh Avenue façade, used for a main entrance and arcade, and continuing to its north and south axis, where it joins a high cross-structure containing the main waiting-room, with the floor one story below the street level, Fig. 2. Immediately east of the main waiting-room and on both sides of the arcade, at the street level, are located the restaurant and lunch-room. The rectangular spaces between these latter, the arcade, and the marginal buildings, are open courts, roofed over at the street level with glass skylights, for train-sheds and for driveways (Fig. 1, Plate LXXXIII) to the baggage-room under the arcade. These driveways communicate with the inclined interior streets, or drives, entered from the north and south ends of the Seventh Avenue front.

Continuing westward from the main waiting-room (Plates LXXXI and LXXXII) and on the same level (one story below the streets), there are two sub-waiting-rooms, and between these and the marginal



PLAN AT STREET LEVEL
NEW YORK STATION

FIG. 1.

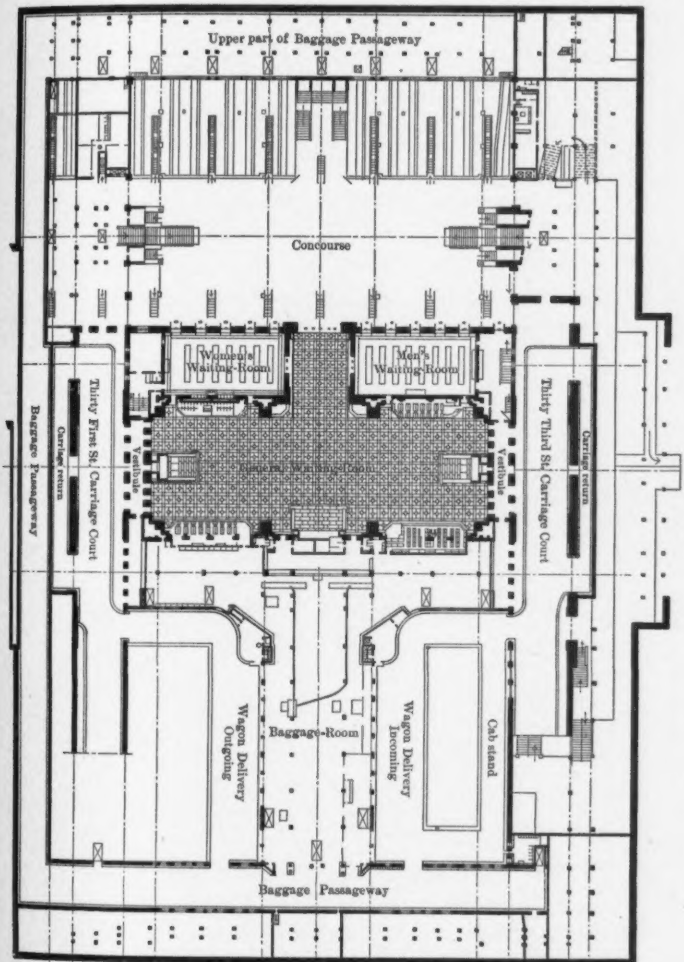
buildings at the west end of the Station, the space is occupied by the main concourse (Fig. 2, Plate LXXXIII), a roofed-over structure of glass, containing the assembly space for outgoing passengers, prior to their admission to the stairways (Fig. 1, Plate LXXXIV), leading down to the track platforms. Under this main concourse there is an exit concourse (Fig. 2, Plate LXXXIV), narrower than the main one, and having stairways at either side from each platform, for incoming passengers, Fig. 3. Both these concourses connect at their respective levels with a two-deck passageway under 33d Street, the entire length of the Station between Seventh and Eighth Avenues, and designed to connect with future rapid-transit subways in either of these avenues. At present this passageway is used for intercommunication with the Long Island section of the station, elsewhere referred to, and for an entrance and exit to 34th Street.

The marginal buildings, on the Seventh Avenue front, above the street level, are used for stores, offices, and entrances to the driveways. On the side streets, as far west as the concourse, the first two stories are given up to driveway spaces, the ceiling being at the attic floor level. West of the driveways the buildings contain offices and the operating staff facilities (see Figs. 4, 5, and 6).

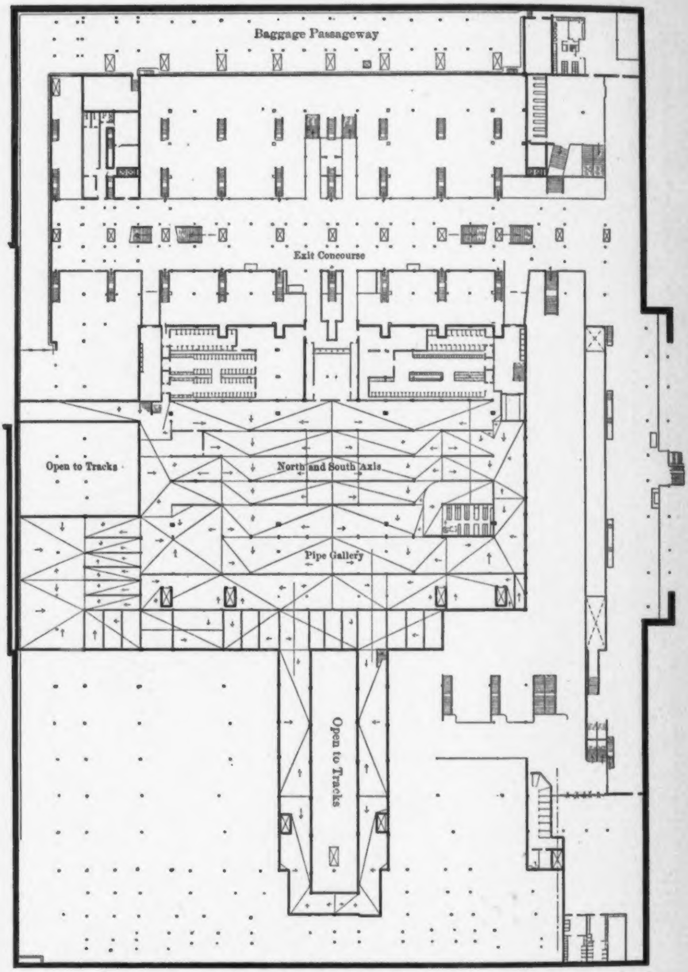
The central vestibule of the Seventh Avenue façade may be considered as the main foot-passenger entrance, leading from which is the arcade, flanked by shops on either side; thence down one floor level by the main stairway to the main waiting-room, in which are the ticket-offices and parcel-rooms, the baggage-checking booth, and other minor facilities. The waiting passenger may then proceed to the sub-waiting-rooms (smoking or non-smoking), where seats are provided; or, without retracing his steps, may enter the main concourse to the west, where the gates leading to the outgoing train platform stairs are located. Both the main hall and the concourse may be entered from two side streets, and the concourse from Eighth Avenue as well. Fig. 1, Plate LXXXV, is a view of the Eighth Avenue façade.

Carriage passengers enter the building from the south end of the Seventh Avenue front by a driveway leading down to the waiting-room and on its level, and outgoing carriage passengers leave by a similar driveway at the north side of the building. These driveways are also used for the wagon delivery of baggage to and from the baggage-room.

To accommodate the large number of suburban and commuter



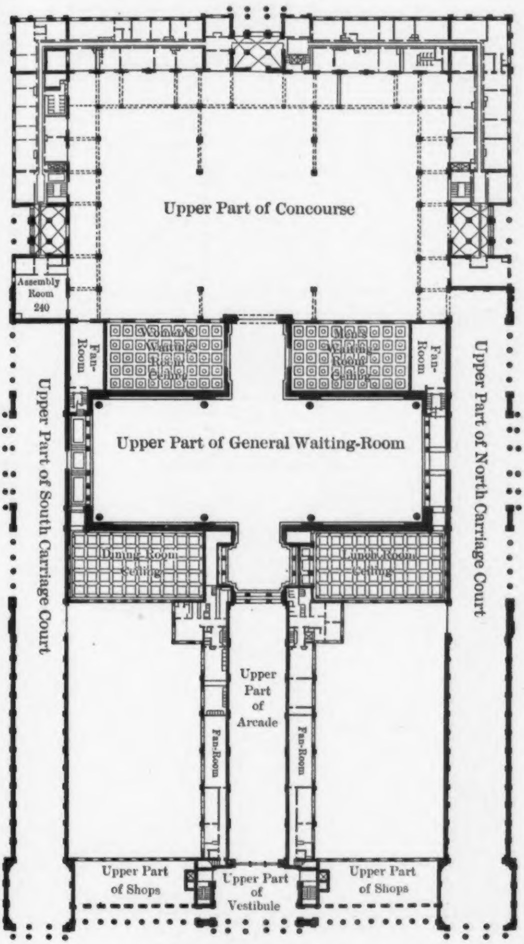
PLAN AT WAITING ROOM LEVEL
NEW YORK STATION
FIG. 2.



PLAN AT EXIT CONCOURSE LEVEL

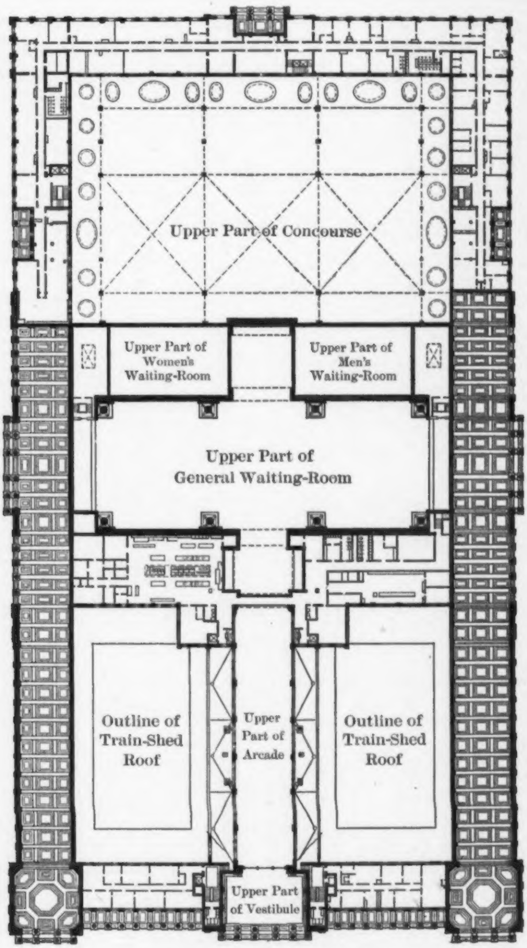
NEW YORK STATION

FIG. 3.



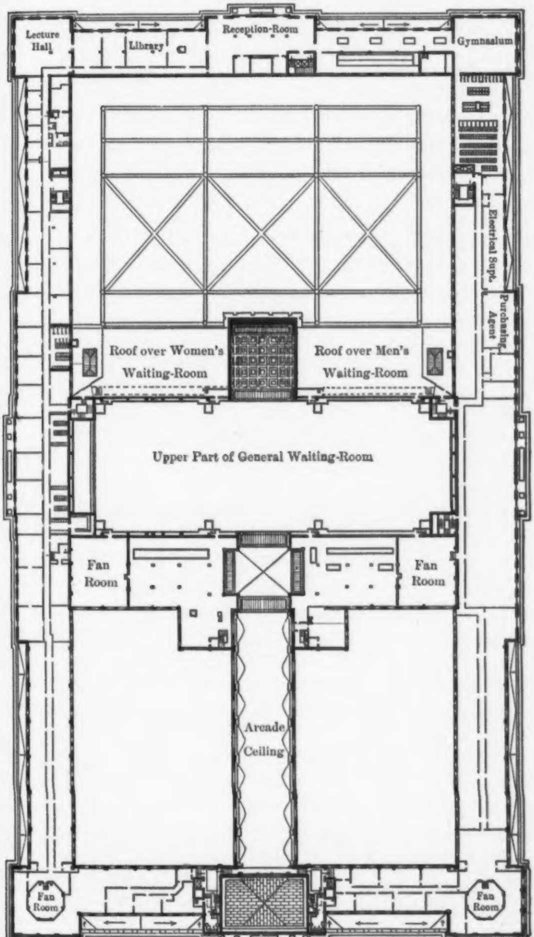
PLAN AT SECOND FLOOR LEVEL
NEW YORK STATION

FIG. 4



PLAN AT THIRD FLOOR LEVEL
NEW YORK STATION

FIG. 5.



PLAN AT ATTIC LEVEL
NEW YORK STATION

FIG. 6.

passengers of the Long Island Railroad, a practically independent station, within the main station, has been provided. This is at the north side, under and adjoining 33d Street. It is entered at the Seventh Avenue corner, by the driveway, by a stairway from 33d Street, or by an entrance and exit from 34th Street, midway between Seventh and Eighth Avenues, and there is a separate waiting-room, with the usual facilities, a wide departure platform, and a concourse communicating with other platforms.

Architecture.—The following description of the architectural motif of the building design has been kindly furnished by Mr. W. Symmes Richardson, of Messrs. McKim, Mead, and White, the member of that firm who was especially charged with working out this problem.

"In designing the Pennsylvania Station, an attempt has been made, not only to secure operating efficiency for one of the largest railway stations in the world, but also to obtain an outward appearance expressive of its use, and of a monumental character. The problem involved was unusual, as the tracks are situated so far below the surface of the street that it was not possible to adopt any of the types of station buildings familiar in modern architecture. The exposed train-shed, with its large semicircular ends of glass, has become, during the last century, a form recognized by the layman as the railway type, and such features at the ends of the avenues of our modern cities suggest a great terminal, even to a stranger, when seen for the first time. Of such a character are the Gare de l'Est, the Gare Montparnasse, and the Gare du Nord, in Paris, the stations at Frankfort and Dresden, and, in fact, most of the principal stations of Continental Europe, as well as the splendid train-sheds of the Pennsylvania Railroad Company in Jersey City and Philadelphia.

"Not only did the architects desire to give an adequate railway expression to the exterior, but they recognized the equal importance of giving the building the appearance of a monumental gateway and entrance to one of the great metropolitan cities of the world. This idea, in their opinion, has not always received the recognition which it deserves in the solution of problems of this character.

"For inspiration, the great buildings of ancient Rome were carefully studied, and particularly such buildings as the Baths of Caracalla, of Titus, and of Diocletian, and the Basilica of Constantine, which are the greatest examples in architectural history of large roofed-in areas adapted to assemblages of people. Moreover, the conditions of modern American life, in which undertakings of great magnitude and scale are carried through, involving interests in all parts of the world, are

more nearly akin to the life of the Roman Empire than that of any other known civilization. It seemed, therefore, fitting and appropriate in every way that the type of architecture adopted should be a development from Roman models, and while the building is of necessity, on account of the requirements of its uses, different from any building known to have been previously built, its inspiration can be directly traced to the great buildings of the Roman Empire.

"To obtain the largest possible expression, simple materials have been used throughout. The exterior being entirely of granite, all unnecessary detail of ornamentation was omitted, and it has been hoped, considering the variegated character and style of the modern architecture of American cities, that in this way the monumental mass and scale of the building has been maintained in relation to its surroundings. The design is of Roman Doric, surrounded by an attic, with a colonnade along the Seventh Avenue front, and with colonnades on the other sides marking the principal entrances. To avoid monotony of effect in a building of such unusual frontage, the attic is broken into pavilions of varying heights, marking the important entrances. In the center of the rectangle, and dominating the entire structure, rises the wall of the main waiting-room, the largest room of its kind in existence. This wall is treated as a background to the buildings facing the street, and is broken simply by eight large semicircular openings of glass, each nearly 75 ft. in diameter, which light the room and give to the building, when seen from a distance, something of the railway character above referred to. Apart from the practical consideration of obtaining adequately roofed-in areas, this room was primarily created to give the exterior of the building as distinctive a railway expression as was possible, considering the limitations of the problem.

"At the north and south ends of the Seventh Avenue front are porticos leading to inclined descending driveways, forming entrances for carriages, which pass between the columns in the same way as in the Brandenburg Gate in Berlin, through which a great part of the traffic enters that city.

"The official foot entrance to the station is in the center of the Seventh Avenue front, opposite West 32d Street. This leads directly to the general waiting-room, in the center of the building, through an arcade, somewhat similar in scale and idea to the famous arcades of Milan and Naples, Italy. The main waiting-room is comparable in dimensions to the nave of St. Peter's Cathedral, in Rome. At the entrance to the waiting-room is a stairway 40 ft. wide, at the side of which is a niche containing the statue of the late A. J. Cassatt, President of the Pennsylvania Railroad, and the dominant personality in the tunnel and station project. The motif of the waiting-room design was suggested by the great halls of the baths of ancient Rome,

above referred to, and consists of eight Corinthian columns, 7 ft. in diameter and 60 ft. high, standing on pedestals, and supporting the coffered vaulted ceiling. At the north and south ends of the rooms are colonnades of single Ionic columns, 31 ft. high, directly approached by bridges over the carriage driveways, from the central entrances on West 31st and West 33d Streets, and from which ample staircases lead to the floor of the room. The sub-waiting-rooms, opening into the retiring-rooms, are proportioned to the magnitude of the central room. The connecting openings are made as large as possible, and frequently are of screens of clear glass of great dimension, permitting comprehensive perspective views, not only of splendid architectural effect, but of great assistance as a guide to the movements of the traveling public. For the interior, the architects have selected a Roman travertine stone, brought from the quarries near Tivoli, Italy. Of this stone, the exterior of the Colosseum, the Tomb of Hadrian (now the castle of St. Angelo), the Quirinal Palace, the Cathedral of St. Peter's, and nearly all the churches and most of the palaces of Rome are built. Considered purely from the structural standpoint, it is one of the finest building stones known, but its selection for this building, for which it has been imported into this country for the first time, was due principally to its beautiful, warm, sunny color, and its tendency to take a polish and improve in appearance by contact and use rather than to absorb dirt, as is the case with so many of the limestones in common use both here and abroad. The stone, moreover, has a very interesting visible structure, which, in a building of such large dimensions, tends to give a more robust character and texture than it is possible to obtain in most other materials. A color motif has been given to the room by the insertion of conventionalized maps in the six large panels below the lunette windows; these maps were painted by Mr. Jules Guerin.

"The concourse itself forms a courtyard with granite walls, enclosed by an iron and glass roof, forming intersecting barrel arches surrounded on three sides by tile domes against the walls of the building. The structural steelwork here is of an open latticed design, without ornament, the architectural effect being obtained by a careful study of the proportions and form of the structural members required. Here the architects have attempted to give to the structural steel a straightforward and adequate architectural expression, and while the design is quite different from anything yet built, it is suggestive in many ways of the train-sheds in the famous stations at Frankfort and Dresden, Germany. On the easterly side of the concourse is the continuous façade of the waiting-room, with semicircular openings, comparable in extent and scale to the Boston Public Library.

"The design, fabrication, and erection of the concourse roof introduced novel problems. It was the desire of the architects to give the structural steel a dignified expression of design, and also to obtain an

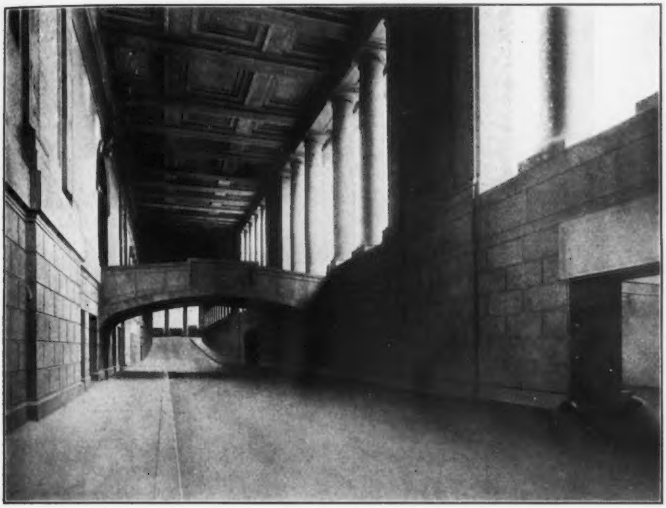


FIG. 1.—THIRTY-FIRST STREET CARRIAGE DRIVEWAY.

FIG. 2.—MAIN CONCOURSE.

appropriate transition between the purely architectural lines and structural materials of the general waiting-room and adjoining rooms and the purely utilitarian and structural treatment of the railway operating features of the yards, such as the tracks, viaducts, etc., that is to say, the leading by an easy and unconscious gradation of effect from the monumental side of the Station to the utilitarian. To accomplish this result the main architectural lines of the concourse roof were first determined, namely, the location of the columns, arches, and domes, and the general height and breadth of the intersecting members; the steel engineer being then given the problem of designing a structure to conform to the architectural lines outlined, the detail being a question of good proportion and adjustment from both points of view. The type and scale of lattice work, as well as the lines and sizes of the arches, notably the variation in depth between the spring and top lines of the arches, as well as varying widths between the diagonal ribs and the vault lines, was suggested to the engineer to obtain a variety of effect and to avoid the monotony which would result in the assembling of arches of similar forms and dimensions. To obtain the expression of these architectural features in steel, necessitated the use of an excess of material over what would be required by ordinary trussing to cover the area in question, but the excess amount of material was considered justifiable to fulfill the motives above referred to. The design of this difficult piece of roofing was due to the joint efforts of the Architects, Westinghouse, Church, Kerr and Company, and Messrs. Purdy and Henderson, Engineers.

"Throughout there has been a consistent and continuous effort to maintain a unity and simplicity of design, so that the structure will count as a whole of many inter-related parts of similar scale. Ornament has been very sparingly used, and there is no attempt at decorative art, except for the color effect of the maps in the main waiting-room. The interior of the building is practically a monotone, it being the idea of the architects that a building devoted to railway purposes should be made of permanent and durable materials of simple character and capable of the easiest maintenance. The light buff of the travertine stone has formed the keynote of the color scheme for the plaster walls and ceilings, the larger ceilings having a pigment in the plaster to give a permanent stain, so that the necessity and inconvenience of repainting is reduced to a minimum. In the few places where decorative sculpture is used, such as the clocks over the main entrances, the eagles and bas-relief panels adjacent, and the large keystones on the exterior of the general waiting-room and over the arches leading from this room to the arcade and concourse, the work was placed in the hands of Mr. A. A. Weinman, a sculptor of reputation, who has given to the ornament and figures a distinct individuality appropriate to the uses of the building."

The following is a list of the principal building subdivisions, with spaces allowed for facilities:

Length of building, east and west	789 ft.
" " " north and south	430 "
General height from sidewalk	76 "
Extreme " " "	153 "
Height, interior of waiting-room	150 "
" " " dining- and lunch-rooms	32 "
" " " sub-waiting-rooms	56 "
" of concourse	100 "
" " exit concourse	11 "

	Dimensions.	Area, in square feet.
Concourse court	340 by 210 ft.	71 400
Concourse floor	475 " 125 "	60 000
Exit concourse floor	480 " 60 "	28 800
33d St. passageway, Seventh to Eighth Ave	654 " 30 "	20 000
Main waiting-room floor	300 " 110 "	33 000
Arcade	220 " 40 "	8 800
East baggage-room (T-shaped) (total area)	246 " 90 "	34 000
West baggage-room	321 " 50 "	16 000
Train-sheds (two, dimensions each)	216 " 112 "	48 384
Standing room for cabs (exit side)		Capacity 25
Lunch- and dining-rooms (two, each)	115 " 60 "	6 900
Sub-waiting-rooms (two, each)	100 " 60 "	6 000
" " " total seating capacity		700 persons
Women's retiring-room	30 " 38 "	1 140
Seventh Avenue shops (two, each)	100 " 35 "	3 500
Arcade shops (two sides, each)	184 " 76 "	28 000
Barber shop	50 " 30 "	1 500
Waiting-room ticket offices	20 windows.	2 400
Carriage driveway, 33d Street	552 by 45 "	24 840
" " 31st Street	530 " 41 "	21 730
Sidewalks around building	2 650 " 30 to 40 ft.	90 000
Women's main toilets		3 140
Men's " "		3 600
Hospital Department		1 400

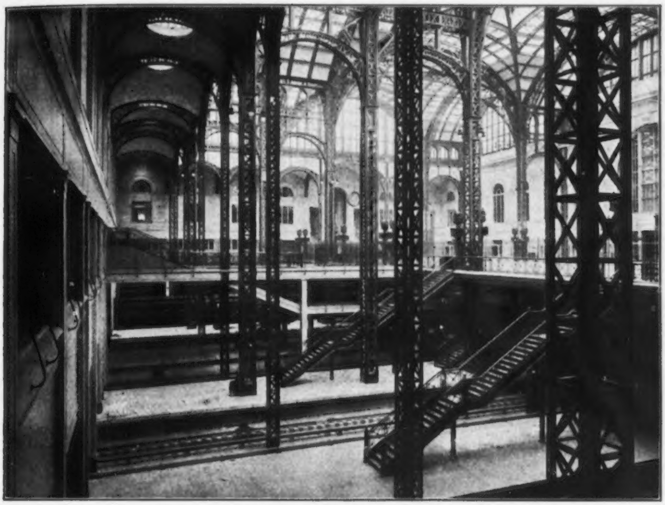


FIG. 1.—CONCOURSE, SHOWING STAIRWAYS TO PLATFORMS.

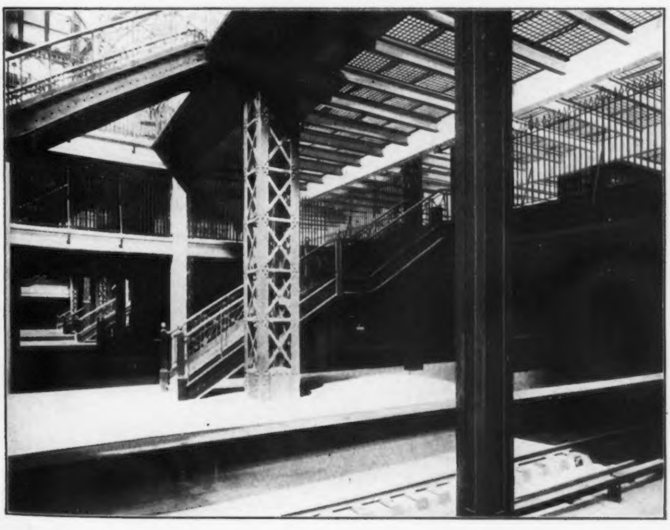


FIG. 2.—PLATFORMS AND STAIRWAY TO EXIT CONCOURSE.

9

	Area, in square feet.
Police Department	827
Funeral-rooms	600
Parcel-room	2 780
Office space, 1st floor, west of waiting-room	15 850
" " 2d floor, west of waiting-room	20 270
" " 3d floor, west of waiting-room	31 500
" " Seventh Avenue, front, two floors	21 500
Y. M. C. A., attic floor	16 800
Bunk-rooms, " "	10 200
Unassigned space, attic floor	27 800
Kitchen and store-rooms	15 000
Ticket offices, main waiting-room	2 344
Ticket offices, Long Island section	2 870

	No.
Passenger elevators to track platforms	11
Baggage lifts	21
Stairways to track platforms	48
News-stands	8
Boot-black stands	7
Clocks	44

General Constructive Features.

It has been the aim to make the building thoroughly fire-proof. Practically no combustible materials have been used in the construction or furnishings of the public rooms, baggage-rooms, or spaces devoted to railway uses below the street level; wood trim is used only for the offices.

Steelwork.—The designing of the building framework is described in detail in the paper by Messrs. Francis and O'Brien. It called for the fabrication of about 27 000 tons of structural steel, in large part of special design, there being little duplication for the different sections of the building or on the different floors.

Granite.—The exterior is of curtain-wall construction, with a granite face. The granite is known as "pink Milford," and the entire product of the Connecticut quarry was engaged. For the exterior, 490 000 cu. ft. of cut stone were used, and 60 000 cu. ft. for the interior of the building. This granite was quarried and cut within a period of 18 months, stored at the quarry, and shipped as needed. The setting of the stonework required 13 months, the average rate being 10 000 cu. ft. per week. The ashlar varies from 8 to 12 in. in thickness, and each stone is anchored by two bronze clips. The setting is in "non-staining"

cement. The columns are built up of granite drums, 4 ft. 6 in. in diameter, having an average depth of 6 ft., and weighing from 4 to 6 tons.

Brickwork.—About 15 000 000 common brick were used in the wall construction. In addition, about 1 100 000 cream-colored mottled brick were used for facing the driveways. Gray wire-cut brick were used for the walls of the train-sheds, the west arm of the main waiting-room, and the various parapet walls of the roofs.

Enameled brick were used in the carriage driveway halls, baggage-checking and parcel-rooms, ticket office and cab offices, for facing the retaining walls under 33d Street, and in the elevator shafts throughout the building.

The driveways are paved with a special grade of re-pressed vitrified clinker brick, the total number used being 650 000. The brick was selected, after careful investigation of different pavings, with the view of obtaining a surface which would give proper foothold for horses on the grade and be durable under traffic. This brick was purchased subject to the requirements that the maximum absorption should not exceed 3%, and that the crushing strength should not be less than 4 000 lb. per sq. in. There were two sizes, the larger were 4 by $9\frac{1}{4}$ by 4 in., with square edges, and were used on the level portions of the driveways; the others were $2\frac{1}{2}$ by 7 by $2\frac{3}{8}$ in., with beveled edges, and were used on the inclined portions. The floor was prepared for the brick by laying a 1-in. foundation course of cement mortar to receive the water-proofing, and this was covered with a cement course of the same thickness. Across the width of the driveways concrete ribs were laid at intervals of about 7 ft., over which the water-proofing was extended, and the trays formed by these concrete ribs were filled with sand 3 in. in depth. On this was laid a 6-in. stone-concrete foundation to receive the paving brick, laid in cement mortar. These precautions were adopted to reduce the noise of passing vehicles to a minimum, and to prevent the pavement from moving down the incline.

Interior Cut Stone.—All walls, lintels, and copings are of Bedford stone. The interiors of the arcade and of the main waiting-room are finished partly in travertine, and partly with an artificial cement composition, devised by Mr. Paul Denivelle to produce the effect of real travertine; it is composed of Berkshire white and ordinary cement, white quartz sand, and iron oxides, compounded so as to produce the

FIG. 1.—EIGHTH AVENUE FAÇADE OF STATION BUILDING.

FIG. 2.—CONCOURSE ROOF CONSTRUCTION.

peculiar lining, voids, and color blends characteristic of the genuine travertine. The blocks were cast in moulds, the slabs being 2½ in. in thickness, and having reinforcing material and anchors for attaching to the walls. The main waiting-room ceiling is of plaster, in deep octagonal coffers, which were cast in moulds on the scaffolding used for the general construction of the waiting-room roof and interior finish. A certain amount of coloring matter added to the plaster makes the tone of the ceiling blend and harmonize with the travertine walls, thus requiring no external decoration. The coffers are 10 ft. in size, are reinforced with steel rods and wire mesh, and are hung from the overhead steel furring by steel anchors.

The exteriors of the ticket offices, parcel-rooms, and booths in the main and sub-waiting-rooms, as well as the trim, partitions, counters, etc., in the dining- and lunch-rooms are of Botticino marble. The public toilet-rooms have trim and partitions of Carrara glass, a milk-white material which is non-absorbent. The trim in the office toilets is of pink Tennessee marble, and this material is used for the wainscots in the hallways.

Fire-Proofing.—A reinforced concrete flat-arch system is used for the floors. The minimum thickness of concrete surrounding the reinforcing rods is four times the diameter of the rods. In general, spans of 6 ft. or more in floors and roofs are of stone concrete in slabs 5 in. thick, and spans of less than 6 ft. are of cinder concrete, with the exception of all tiers below the street level, where stone concrete is used. The reinforcing rods are 4½ in. from center to center, and the ends are turned down over the top flanges of the beams.

Loading.—The following live loads were used in designing the building steel and the floor system:

	Pounds per square foot.
Waiting-room, main and exit concourses....	150
All other floors below street level..........	300
The entire street floor.....................	150
Sidewalks	300
Floors in kitchen.........................	150
All other floors above street................	100
Roofs pitching more than 20°..............	30
All other roofs...........................	50

Column Protection.—All columns under and supporting the station in any way are protected by fire-proofing, in accordance with the Regu-

lations of the City Building Department. This fire-proofing consists of a concrete grout filled in between the column and a ½-in. steel-plate jacket which surrounds it for a height of 8 ft. 6 in. above the platform level; above this casing the concrete surface is exposed.

Ornamental Iron.—About 2 500 tons of ornamental ironwork, including cast iron and steel, were used in the interior fittings, especially in the stairways, fences, and in the concourse enclosures for the elevators and lifts.

Vault Lights.—About 155 000 sq. ft. of vault-light construction were used in and around the building. This unusual amount was required to secure light under the sidewalks for the interior passageways and under the concourse floor for the exit concourse and the platforms. The exterior vault lights are of the reinforced-concrete type, with circular glass prisms set with lead rings around each, to prevent shaling. The interior vault lights are of the same type, without rings, except that square instead of round glass was used.

Roofing.—In general the extensive roofing system is of tile covered with No. 16 sheet metal, in part with flat and in part with cleated, or standing, seams. Instead of copper, "Monel metal," an alloy of 60% nickel and 40% copper, was used. This metal is a natural alloy, having approximately the composition of "German silver," and has the well-known non-corrosive properties of that alloy; while strong, it can be readily flanged and soldered, and weathers to an agreeable tone. Of this metal 150 tons were used. The flat roofs are covered with self-glazed tile 1 in. thick. Fig. 2, Plate LXXXV, is a view of the concourse roof construction.

Interior Woodwork.—The furniture in the lunch- and dining-rooms is of Italian walnut; the office trim is of Betula walnut; and the trim in kitchens and service-rooms is of ash. All doors in the public entrances and rooms have long, clear-glass panels; communicating doors between offices have long, raised panels. The doors from corridors to offices are the two-panel type, with transoms above. Base, chair rail, and picture mouldings are used in all offices; and in corridor walls, where borrowed light is required, partition sash have been set.

Flooring.—Maple flooring is used throughout in the offices, and in the Y. M. C. A. section. The general waiting-room and sub-waiting-rooms, lunch- and dining-rooms, Seventh Avenue vestibule, arcade, public lavatories, and barber shop, have marble floors. Cork floors have

been used in the spaces where employees stand, such as the ticket offices, serving pantries, and behind lunch and cigar counters. Granolithic floors are used in the baggage-room, baggage passageway, and kitchens.

Building Erection.—The work of preparation for the building construction began with the sub-surface work in the excavated plot, as turned over to this Department by Mr. Noble. As soon as a sufficient area at the track sub-grade was secured, the work of excavating and constructing the substructures and building foundations was begun. This resulted in the successive completion of the foundations, beginning at the southeast corner of the building, and the erection of the steel frame, from this point working in both directions around the outside of the building, until it was enclosed at the Eighth Avenue side. The masonry followed the steel erection, and the building was finally enclosed at about the time when the entire terminal yard area was excavated to sub-grade. All materials were delivered at the site by trucking through the streets, as railroad connections were at the time impracticable.

The building methods were not unusual, aside from the magnitude of the structures, the amount of erection plant required, and the force engaged. The structural steel was stored and sorted in the plot under the building, and erected by cranes. The granite was delivered around the building to timber staging over the sidewalks and supported from the track level; the erecting was done by derricks set on the inside floors. All other materials were delivered in the building as construction progressed. The general waiting-room, because of its great height (150 ft. from floor to ceiling), required the installation of extensive and massive falsework, which would permit of the convenient and expeditious erection of the steel frame and roof trusses, setting the granite, lining the interior walls, hanging the ceiling, and finishing the interior. This falsework was of 12 by 12-in. vertical posts, at 12-ft. centers, braced with 3 by 12-in. planks, thoroughly bolted, and contained about 500 000 ft. b. m. It was erected in six stories, with runways at each floor. The falsework was equipped with stairways and hoists for loading material on platforms at the different floors. Six stiff-leg derricks, each of 20 tons capacity, having 50-ft. booms, were erected on this staging. Because of danger from fire, the falsework was equipped with an elaborate system of high-pressure fire-protection pipes, with hose outlets at every level, and was constantly patroled by firemen.

Furthermore, it was thoroughly wet down twice a week. Throughout the entire building construction, the temporary system of fire protection and patrol service was maintained, and, although a few minor fires occurred, they were arrested before they had time to spread, no damage to the building resulting in any case.

Constructive Data.—The following is a list of the construction dates, and of quantities of the more important materials used in the building:

Building foundations begun	June 1st, 1906.	
First steel column erected	May 27th, 1907.	
First stone of masonry set	June 15th, 1908.	
Finished exterior masonry	July 31st, 1909.	
Building substantially completed	August 1st, 1910.	
Maximum number of men employed	4 240	
Average number of men employed	1 800	
Granite, exterior	490 000	cu. ft.
Granite, miscellaneous and in concourse	60 000	"
Marble, interior	24 000	"
Travertine	71 580	"
Artificial stone	11 600	sq. yd.
Concrete fire-proofing, cinder	243 000	cu. ft.
Concrete fire-proofing, stone	720 000	"
Granolithic floors	310 000	sq. ft.
Marble floors	85 000	"
Cork floors	11 000	"
Maple floors	147 000	"
Terrazzo floors	10 000	"
Vault lights	155 000	"
Brickwork, all kinds	17 000 000	brick.
Terra cotta furring and partitions	600 000	sq. ft.
Roofing, metal	300 000	"
Roofing, tile	150 000	"
Roofing, skylights	83 000	"
Structural steel	27 000	tons.
Ornamental iron	2 500	"
Glazing	80 000	sq. ft.
Plastering	85 400	"
Painting (area)	2 800 000	"
Cement	64 000	bbl.

Station Facilities.

Of the more important operating features of the building, those involving engineering problems will be described in some detail. They

were planned only after extended Committee and engineering consideration, to utilize to the fullest the available space in the building, with the greatest flexibility of operative methods, and for the future growth of business up to the capacity of the terminal as a whole.

Operating Arrangement.—The station tracks are arranged for both through and stub-end operation, but, for the majority of the movements, it may be considered a stub-end station. Through trains on both the Pennsylvania and Long Island Railroads are handled by electric locomotives; suburban trains of the Long Island Railroad, by multiple-unit motor cars. There are eleven station platforms, serving twenty-one tracks; of the latter, sixteen (Nos. 1 to 16, inclusive, numbering from the south side) are normally assigned to the Pennsylvania service, and all communicate with the North River Tunnels. The remaining five tracks to the north (Nos. 17 to 21, inclusive) are assigned to the Long Island service.

Pennsylvania Railroad trains—except certain short-distance expresses from Philadelphia, and certain locals—after unloading, proceed through the 32d Street and East River Tunnels to a large terminal yard in Long Island City, where they are turned, cleaned, and made up for the return trip. The short-distance expresses are turned and stored in the station yard. All Long Island trains are at present cared for in the station yard; the expresses are switched into the north yard, and locals, after unloading, are tail-switched from the two tracks adjoining the incoming platform (No. 11) to the tracks adjoining the outgoing platform (No. 10). In case of necessity, either platform, No. 10 or No. 11, may be used for either arriving or departing passengers, or platforms Nos. 8 and 9 may be similarly utilized. The 33d Street Tunnels are normally used for Long Island Railroad business exclusively, these tunnels communicating with tracks Nos. 14 to 21, inclusive, but the 32d Street Tunnels may be used in emergencies, thus making all station tracks, except the southernmost four, available for Long Island Railroad service.

Platforms.—The original plan of the station contemplated following the usual American practice of making track platforms about 9 in. high above the rails. Detailed development of the station facilities, however, indicated that low platforms are open to some serious objections, and a departure was decided on in the adoption of the English standard practice, making the platforms flush with the car floor, a

decision which may have a far-reaching effect in the future on the practice in other stations in America. The general features of this platform are shown on the lower part of Plate LXXXVIII. The controlling reasons for the adoption of high platforms in the New York Station were:

(*a*) The greater ease in loading and unloading cars; an advantage which will be appreciated by passengers who are infirm, or who have hand-baggage;

(*b*) The saving in time of loading and unloading trains; this will tend to prevent congestion on narrow platforms, and is an important factor in utilizing to the fullest the station facilities, especially in local excursion and commuter services;

(*c*) A saving of about 4 ft. in the vertical lift between the platforms and the street; this is also an important advantage in a station depressed below the street level;

(*d*) The elimination of the dangerous practice of crossing tracks at grade, a consideration which applies to employees as well as to passengers, and has special force in a station where the view is obstructed by columns, etc.;

(*e*) Incidentally, they permit the convenient use of hydraulic power for operating the elevators and lifts, giving space under the platforms for the machinery and piping; they also provide space for housing the signal and certain other electrical apparatus.

The usual objections cited against high platforms for steam railways had not controlling weight, in the case of this terminal station, because of its location and the type of equipment adopted for other reasons, thus:

(*a*) The new steel cars used for all purposes have vestibules with side-doors arranged so that they can be opened without requiring the trap over the steps to be lifted, and the fascia over the doors is of sufficient height to permit passengers to walk out on the platform level;

(*b*) The difficulty of handling baggage to and from trucks at the cars is minimized by using a special truck, with its platform only 9 in. above the car floor;

(*c*) The arrangement of lifts and cross-trucking subways under the tracks makes it unnecessary to truck across the tracks at grade;

(*d*) The first cost of the high platforms was not excessive, because of the cheapening of other constructive features of the station, such as the lifts, stairways, piping, signals, etc.

There are eleven passenger platforms under the station, varying in width from 20 to 40 ft., and in length from 750 to 1 170 ft. All are "island" platforms, having a track on each side. The total platform length adjacent to passenger tracks is 21 500 ft. In addition, there are "island" platforms west of the Station and under the Post Office which are used exclusively for mail car purposes. Space has also been assigned for two additional platforms at the south side of the yard near Ninth Avenue, for future Express Building purposes. The platforms are of reinforced concrete with edges set 3 ft. 10 in. above the top of the track rails, and 5 ft. 3 in. from the center of the track. These standards allow a normal clearance of 3 in. from the side of the widest car, and place the top edge always somewhat below the car platform, due allowance being made for wear, loading, and variation in equipment.

TABLE 3.—ELEVATORS AND LIFTS.

Elevators, etc.	No.	Size of cars.	Capacity, in pounds.	Capacity, in passengers per hour.	Speed, in feet per minute.	Lift, in feet.
Passenger elevators..	11	5 by 10 ft.	2 500	750	200	17
Baggage lifts.........	21	7 by 15 ft.	7 500	......	100	28
Post Office lifts.......	4	6 by 15 ft.	7 500	......	100	52 to 70
Office elevators.......	10	5 by 5 ft. 10 in.	2 500	......	300	40 to 70
Dumb-waiters........	2	4 by 3 ft.	400	......	200	54
" "	4	2 by 2 ft.	100	......	200	37
Escalator.............	1	Stair 4 ft. wide.	......	9 000	85	25

Water pressure used at hydraulic lifts, 270 lb. per sq. in.

Elevators and Lifts.—The location of the building over the tracks, and the peculiar arrangement of the public spaces and the offices, as well as the great area covered, made the planning of the necessary system of vertical conveyors for passengers and freight a difficult matter. Services were to be provided for:

(1) Passenger elevators from the track platforms;

(2) Baggage lifts between the baggage-room, the platforms, and the subways underneath;

(3) Office elevators from the street level to the floors above;

(4) Service elevators and dumb-waiters between the restaurants and the kitchens;

(5) Moving stairways (or escalators) from the concourse to the street level;

(6) Lifts and conveyors for handling mail from the trucking subways to the main floor of the Post Office.

In general, it was determined that each platform should be provided with a passenger elevator operating between the train level and the exit concourse. It was not possible, because of the plan of the building, to operate these to the street level, nor could they be made of sufficient capacity, without sacrifice of platform space, to handle entire train loads. The arrangement adopted gives one elevator for each platform, eleven in all. Three of these have a lift of 27 ft. 6 in. to the main concourse, and the remaining eight a lift of 17 ft. to the exit concourse only.

Because of the high platforms, baggage trucking cannot be done across the tracks at grade, therefore a very complete system of lifts has been provided between each platform and the baggage-rooms above, as well as to a cross-subway below. Each of the nine long station platforms has been equipped with two lifts, one from the outbound baggage-room on the west side of the building, and one from the inbound baggage-room on the east side. The two short Long Island platforms on the north side of the station have one lift each. The lifts, generally, have a travel of 28 ft. Mail handling to the Post Office, as explained more fully elsewhere, required the installation of four lifts from the platforms to the building proper.

The use of escalators, or moving stairways, from the platforms to the concourse was considered, and, although space was provided for them in the building framing, it was decided to defer their installation until their actual operating necessity was demonstrated. If not needed, they would be objectionable, as they would transport passengers to the main instead of the exit concourse; thus they would cause a conflict of passenger movements, and defeat the chief advantage of the double concourse system. The condition at the north side of the station, however, where large commuter travel from the Long Island Railroad is cared for, is special, and at this point an escalator has been provided, leading passengers from the exit concourse under 33d Street to the street level midway between Seventh and Eighth Avenues. By this means passengers are landed without effort in a private street and near the 34th Street cross-town surface car line.

The selection of a suitable operating means for the entire elevator and lift system was made the subject of much study, as many of the conditions were difficult. The great area to be covered (about 20 acres for the building and yard) indicated that electric distribution of power, rather than hydraulic, would be simpler and cheaper. In fact, in the case of low station platforms, as first intended, it seemed to be essential to adopt electric elevators, as there was, in places, no available room for the piping runs and pressure tanks required for a hydraulic system. In case of the baggage lifts, however, it was desired to secure the advantage of the hydraulic plunger type, because of the ease and accuracy of control, simplicity, and absence of machinery and counterweights over the platforms and tracks. Therefore, when high station platforms were adopted, it was found entirely practicable to use hydraulic baggage lifts and concourse passenger elevators, placing all piping and apparatus in the space under the platforms.

The conditions were somewhat different with the office elevators and kitchen dumb-waiters, as their plungers would interfere with clearances over the tracks, and therefore electric elevators were adopted for these services.

Power for the hydraulic lifts is furnished by pumps in the Service Plant, and current for the electric elevators is taken from the general traction power mains through a special switch-board connection in the Service Plant. The electric elevators, being over the platforms and tracks, required special safety precautions to arrest a falling car or counterweight; therefore, all elevator shafts were provided with air-cushion wells, from 8 to 10 ft. deep, and Cruickshank arresters for the counterweights. Thorough tests were made of the efficiency of these devices on all elevators; for instance, a fully loaded car was cut loose at the top of a shaft, allowed to drop freely 70 ft. into the cushion, and was brought to a stop without spilling water or breaking an egg in the car; the air pressure developed in the cushion was about 16 lb. per sq. in.

Gates and Control.—The gate and control systems for the baggage lifts are worthy of mention. To provide against the possibility of a baggage truck breaking through a lift-gate at the platform level, there are collision-proof gates of steel plates and reinforcing angles at all entrances to the lift shafts. These gates are of the disappearing type,

moving in slots in the hatchways below the platform level. They are partly counterweighted, and are operated by compressed air, controlled through levers on the car and from the outside. A gate can be opened only when a car is at rest at the landing; if a car leaves the landing while the gates are open, they will close automatically. Either gate for a car can be operated independently.

In order to obviate the necessity of having an attendant at each lift, a special apparatus was installed to operate the hydraulic starting mechanism through electric control. This consists of push-buttons, located at each landing and on the car itself, electric circuits to a controller-board, and an electrically-operated pilot-valve on the board, controlling the hydraulic valve mechanism proper of the lifts. A car can thus be called for or sent to any landing automatically by pressing the button for that landing. The car cannot be operated by the push-button control if any hoistway gate is open, and when a car is at rest at a landing and the gate is open, the car-operating rope is locked against movement until the gate is closed; furthermore, after a button has been pushed to send, or to call the car, all other buttons are inoperative until the car has moved to, and come to a stop at, the landing called. If a gate is opened while a car is moving, the car will stop at the next landing toward which it is moving. In addition to this automatic control, the lifts may be operated in the usual way by hand-ropes.

Baggage Handling.—The baggage facilities have been planned for as rapid service as consistent with the very large platform area served, and to avoid long-distance trucking on the platforms, which are necessarily somewhat narrow and obstructed by building columns. Therefore, two baggage-rooms have been provided; one at the east side, adjoining the main waiting-room and the driveways, for delivering to and from wagons, for checking, and for arriving baggage from trains; and one at the west side, adjoining Eighth Avenue, for delivery to trains. The east room contains all the usual facilities for weighing, checking, storage, and offices for the operating force, and for the Transfer Company, and is the one to which the public has access. The west room is chiefly a passageway for reaching the various platform lifts. The two rooms have communication by a trucking passageway under 31st Street and under the Seventh Avenue front of the building. The following data relate to baggage handling, in terms

of amount handled at present in summer; the ultimate capacity of the facilities provided is much greater, of course, than the figures given:

Estimated quantity of baggage handled per hour.	220 pieces.
Total quantity per 24 hours..................	6 025 "
Storage capacity	6 000 "
Length of run from east to west room.........	1 350 ft.
Time required to deliver truck load to car at west end of platform....................	8 min.
Number of baggage scales....................	4
Capacity, total	20 000 lb.
Capacity, weighing	10 000 "

Baggage Trucks.—There are four kinds of baggage trucks for station uses. The special trucks, used for general baggage purposes, were designed and built by the Motive Power Department, at Altoona, and are similar to those in use elsewhere on the road, except that they have drop frames, with floors flush with the track platforms, for greater convenience in loading from the cars. These special trucks are automobile and trailing, both of the same construction, except that the former are equipped with electric motors and storage batteries. The battery is of twelve cells of 200 ampere-hours capacity, with a maximum discharge rate of 50 amperes. The batteries are recharged at a stand in the 31st Street baggage passageway, where hand-cranes, charging racks, and electrical connections, communicating with a switch-board in the Service Plant, have been placed. The charging current is 25 volts, and is supplied by small motor-generators in the above plant, as a part of the auxiliary power system. Other data regarding these trucks are as follows:

Size of platforms.....................	3 ft. 8 in. by 12 ft.
Height above floor....................	$9\frac{1}{2}$ in.
Speed, in miles per hour..............	6
Shortest turn	15 ft. radius.
Weight of truck, light................	2 600 lb.
Capacity of truck.....................	4 000 "

The following trucks are provided for different station purposes:

Electric baggage trucks........................	25
Trailer baggage trucks of the same type, without motors	25
Mail-handling trucks, without motors.............	25
Funeral trucks	6

Train Indicators.—In the main concourse, at the head of the stairs to each track platform, there are gates and illuminated signs describing the destinations and the departure times of trains. There are forty-four of these indicators. They consist of cast-iron columns, 16 ft. high, two at each gate. The top of each column is four-sided, and contains mechanism for moving steel tapes opposite the openings on the four sides simultaneously; on these tapes the numerals from 1 to 10 are enameled. The mechanism is operated by a crank key through vertical rods and gearing from sockets near the bottom of the post; by turning this key the tapes may be set to indicate any desired departure time. The posts also carry a four-sided card box, in which destination signs are displayed; these are placed in a frame, operating in guides in the post, and raised into position by a hoisting-drum mechanism.

Train-Starting System.—As the distance between the gates on the main concourse and the trains at corresponding station platforms is considerable, it was necessary to have a system for quick communication between the gateman, the conductor of the outgoing train, and the train director in the signal cabin, in order to insure prompt control of the starting of trains at the scheduled time.

At the head of the stair leading to the platform there is a push-button and lamp indicator; and on each platform at four different points there is inserted in the column an instrument containing a switch, a push-button, an indicating light, and, higher on the same column, another light. There is an instrument for the same function in the interlocking cabin controlling the train movement out of the station. Fig. 1, Plate LXXXVI, is a view of a column at the platform level, showing the train-starting device and telephone set. All these various devices are interconnected by electric wiring, and operate as follows: About 1 min. before the train is to leave, the conductor inserts a key in the conductor's instrument, thus showing the number of the track from which the announcement is given. The director then moves a lever, which closes the circuit and lights a lamp in the conductor's box and at the platform gate to indicate to both conductor and gateman that the route has been set for the departure of the train. When a gateman closes his gate at the train leaving time, he pushes a button, extinguishing the indicating light and, at the same time, by the lighting of the lamp at the top of the

FIG. 1.—COLUMN AT PLATFORM LEVEL, SHOWING TRAIN-STARTING DEVICE AND TELEPHONE SET.

FIG. 2.—PIPING AND HOT-AIR DUCTS IN WEST BAGGAGE-ROOM.

column, notifies the conductor that the gate is closed. When the passengers are aboard the train, the conductor operates a push-button circuit-breaker, extinguishing all lights and restoring the apparatus to normal.

Clock System.—Electrically-operated and centrally-synchronized clocks have been provided throughout the station and yard; they are distributed as follows: Four clocks, 6 ft. in diameter, on the exterior façades of the building; fourteen, with diameters varying from 18 in. to 15 ft., in the public rooms; twenty-six in various offices, yard buildings, and signal cabins, and one master-clock, in the train despatcher's office, synchronizing all other clocks.

The clocks are of three different types: motor-driven, impulse-driven, and primary or self-contained. The master-clock is equipped with a transmitter and circuit-closing device to transmit operating and synchronizing impulses to the other clocks, and besides being a close time-keeper, is corrected automatically once in each 24 hours from a signal sent out by the United States Observatory at Washington.

The motor-driven clock is the 15-ft. dial instrument in the main waiting-room; its hands move forward slowly each ½ min. The impulse clocks, comprising those in the public rooms, have a jump movement forward each ½ min., by impulses sent out from the master-clock through the medium of a transmitter. The "primary" clocks in the offices have self-contained winding and operating mechanism, with a winding battery within the clock and arranged to be corrected hourly by impulses received from the master-clock. The primary clocks are synchronized in multiple, and the impulse clocks are operated in series.

A central storage battery of twelve cells, in duplicate, provides the necessary source of energy for operating the entire plant. Each battery is sufficient for one week's work, the re-charging being done alternately from a motor generator in the Service Plant. The total current consumption is about 3 ampere-hours per day.

Nearly all the clocks are lighted by reflection from the general illumination of the rooms, but those on the exterior of the building and in the main waiting-room are lighted by electric lamps in the clock cases. The casings of the clocks on the exterior of the building and in the public rooms were designed by the architects, and at each location harmonize with the general finish of the building.

Pneumatic Tubes.—For the prompt dispatch of messages and small packages, between the different buildings throughout the yard and the offices in the station building, a pneumatic-tube carrier system has been installed. It operates at an air pressure of from 2 to 4 lb. per sq. in., the air supply being taken from the compressors in the Service Plant through reducing valves into low-pressure storage tanks, located at various points throughout the yard and building, and thence piped to the tube terminals.

The tubes are of brass, specially drawn, are of various sizes, and have long-radius turns. Each run is of a single tube, having terminals at the ends to serve for either dispatching or receiving the carrier. The terminals are normally open, and, when the carrier is placed in the tube, the door at that end is closed and air automatically admitted. The door remains closed until the carrier reaches the opposite end of the line; there it trips a trigger which opens an electric circuit and de-energizes the electro-magnet which holds the door shut at the sending end.

The carriers are of leather, and of the required sizes to hold messages, baggage checks, packages of tickets, etc., depending on the service. The length of the tube runs varies from 150 to 1 000 ft., the total length of the system aggregating 7 000 ft.

The following are the lines of intercommunication established:

From the telegraph office on the second floor of the Eighth Avenue building, 2¼-in. lines to each of the following:
- Two Pullman offices in general waiting hall.
- Baggage Agent's office in baggage-room.
- Station Master's office at northwest corner of concourse.
- Assistant Yard Master's office in yard under Post Office.

From the two telegraph offices in the general waiting hall, 2¼-in. lines to:
- Each Pullman office in general waiting hall.

From Assistant Yard Master's office in yard, 2¼-in. line to:
- Signal Cabin "A" in the yard.

From Signal Cabin "A," 2¼-in. line to:
- Car Inspector's office in yard.

From the ticket stock-room, 5-in. lines to:
- Two general ticket offices in general waiting hall.

From Assistant Baggage Master's booth in baggage-room, 4-in. line to:
- Two baggage-checking desks in baggage-room.

Lighting.—The engineering considerations leading to the selection of the type of lighting for the Station are discussed in connection with the design of the Service Plant. It is there stated that small lighting units, rather than powerful arc lamps, were adopted. This decision was reached, not only because of the good architectural effect and the agreeable quality of small lights, but because of the effective diffusion secured from numerous sources of light. In general, the treatment adopted for different spaces is as follows:

The street lighting is by lanterns of moderate power, set on posts 16 ft. high, and 45 ft. apart around the building; this system is used extensively in Europe, especially in Paris. The arcade is lighted by side brackets containing clusters of Nernst lamps. The public rooms, except the main waiting-room, are lighted by ceiling chandeliers, consisting of rings of Nernst lamps; the main waiting-room, because of its great height, is lighted near the floor only by two rows of cluster lamps on posts, with a limited amount of side-bracket lighting for wall illumination; the ceiling of this room is intended to be left in semi-obscurity, thus increasing the effect of height at night. The concourse, having its roof and floor largely of glass and ironwork, was a difficult space to light agreeably and effectively; after experiments with various kinds of lights, it was decided that rings of Nernst lamps around the columns, and ring chandeliers for the central spaces, gave the best effect.

For general illumination, the offices are equipped with ceiling lamps; local desk circuits, however, are provided in the base-boards of each room. The platforms are lighted by Nernst units about 20 ft. apart and as high above the floor as local conditions permit. The intensity of the platform lighting, as will be noted from the list, is relatively low compared with other spaces, but is ample.

The question of the best type of lamp for lighting the Station was given much consideration. At the time when decision was necessary, choice lay between the ordinary carbon filament, the metalized carbon filament, and the Nernst. This latter form uses a "glower," made of a mixture of rare metallic oxides, and is not sealed in an exhausted bulb, as are ordinary incandescents. The Nernst lamp gives light of agreeable quality, and its construction is such that the light is radiated from the lower hemisphere without the use of reflectors, thus readily adapting it to general illumination from overhead sources; furthermore, it was decided to be more economical than other forms available.

For these reasons it was decided to adopt it for all general illumination of the Station; in certain special cases, however, such as for the lamp-post clusters in the main waiting-room, for desks in the offices, etc., incandescent lamps, either carbon or tungsten, are used.

Electric current, used in the Station for lighting and motors, is distributed at the required voltages from a main switch-board in the Service Plant through cables to sub-switch-boards, located at centers of the main divisions of the Station; from these boards it is further distributed to local boards in the smaller sections, or in individual rooms, and finally to the room switches in the offices, or to large groups of lights in the public rooms. All the larger public rooms are supplied with current from duplicate sets of feeders, one set of which is connected to an emergency bus in the Service Plant. The main feeders from the Service Plant are carried through the pipe subways under the tracks and in special pipe and wire shafts built in the Station Building walls. The branch circuits are generally carried on top of the concrete floor arches and built into partitions. All feeders and sub-feeders are three-phase; branch circuits are single-phase. The lighting of public rooms is arranged so that half the lights are supplied by each of two feeders.

Miscellaneous power distribution is arranged in a similar manner, the power to the heating and ventilating motors throughout the building being distributed to the panels in these rooms from the subboards which are fed direct from the Service Plant.

Further data are given below:

Total number of lighting fixtures in Station....	21 000
Total equivalent combined candle-power of lights in Station	335 000
Feet of conduit used..........................	310 000
Feet of wire (No. 14 to 600 000 cir. mils).......	690 000
Candle-power (mean hemispherical) per square foot:	
Main waiting-room........................	0.45
Other public rooms.......................	0.60
Offices (general lighting)..................	1.25
Main concourse............................	0.35
Platforms	0.25

Heating and Ventilating.—The heating and ventilating is one of the most important as well as one of the most complicated of the service requirements, and covers the heating of the main station as well

as of the numerous buildings in the terminal yard, and the heating supply for cars standing in the yard, over an area of about 28 acres. The type of heating had a bearing, not only on the kind and quantity of apparatus required, but on the design and construction of the Station Building itself, and therefore the general heating scheme had to be determined prior to the construction of the building, and with an intimate acquaintance of the plans, in order that its service could be made to harmonize therewith.

The problem involved primarily the heating of a building having very large cubical contents, but especially one covering an unusually large ground area, and the fact that the building has no basement or cellar proper introduced special difficulties in installing large heating mains and radiating apparatus. The rooms in the building vary in size from the main waiting-room, 110 by 300 ft. and 150 ft. high, down to the usual dimensions of offices; and the occupancy covers the composite requirements of a railway station, a restaurant, and an office building. Many of the rooms are designed to house large numbers of people, some of the rooms have only indirect communication by windows with the outside atmosphere, and many are below the street level; therefore, it appeared desirable to use a forced-draft heating system, so that the air might be taken from suitable places and that proper ventilation could be had in summer as well as in winter, provided it could be installed and operated at a moderate cost as compared with other practicable methods.

To determine the best system of heating, all things considered, as applied to the local conditions, elaborate calculations and preliminary plans were made for various systems, as follows:

(*a*) Direct radiation in the various rooms, without forced ventilation;
(*b*) Indirect heating from pipe stacks located at central points, the warmed air being distributed through ducts by forced draft;
(*c*) A combination of part direct and part indirect heating.

It appeared that portions of the Station, such as the waiting-rooms, kitchens, restaurants, and toilets, where forced heating and ventilation were desirable, if not actually necessary, comprised at least two-thirds of the total area to be dealt with; and that if the indirect system should be used for places where it is essential, it could be extended to embrace the smaller spaces, such as the offices, without introducing

prohibitive complication or without materially increasing the first cost of installation over that of the combined direct-indirect system. The conclusion was reached, therefore, that the indirect system with forced ventilation, both by draft and suction, should be adopted for all spaces except special isolated places, such as the baggage-rooms, which cannot be entirely closed by doors, and in cases of the small isolated buildings in the yard, where the direct system of radiation from pipes in the rooms should be used.

The next consideration was that of the medium of supplying the heat from a central point, the source of heat being the boilers in the 31st Street Service Plant. It was concluded that low-pressure steam, either live or exhaust, conducted to the building through pipes, was impracticable, on account of the great area to be served, the very large dimensions of the pipe mains, pipe expansion troubles, and the lack of opportunity for draining properly the complicated system of return piping. Furthermore, exhaust steam thus used would cause excessive back pressure on the engines; live steam at high pressure would reduce the diameter of some of the pipes, but would still leave unsettled the question of proper drainage, and would make it difficult to control the pressure at widely separated points. The cost of operation would also be high, as no advantage could be taken of the economy to be gained by passing the steam first through the engines to produce light or power. The remaining method, namely, the use of water heated at a central point near the engines by exhaust steam from them, and distributed by pumping through a piping system to locally placed stacks in the building, appeared to be best. Such a system involves small piping only, is free from drainage troubles, is convenient for regulation, and gives the best quality of heat under varying weather conditions.

While, as above indicated, it was concluded that the water system of distributing heat was the only one filling the practical necessities of this particular case, an estimate was made of the comparative first cost of all systems, and it was found that the three available did not differ greatly in this respect, and that the indirect system with hot water could be installed at as low first cost as that of any other.

Comparison was made of the operating cost of both the direct and indirect systems, on the basis of both live and exhaust steam-heating means. It was found that the lowest operating cost would be obtained by using exhaust steam to heat water circulation with direct-heating

radiators in the rooms. Forced ventilation, however, which as above stated was considered a necessity, would not entail a greatly increased operating cost by the use of indirect-heating stacks, as the supply of exhaust steam would be ample for all except the severest weather.

Steam from the boilers in the Service Plant is passed through the various engines used for lighting, for air compressors, pumps, etc., and the exhaust is taken into tubular water heaters. Motor-driven centrifugal pumps circulate water through these heaters by the closed-pipe system into and through nine heating chambers in various parts of the Station Building. From these the water returns to the circulating tanks and is used again. Connections are also made to the water heaters, so that live steam can be used when necessary. Through the heating stacks in the building fresh air is delivered from hoods on the roof, being drawn by fans and forced through a system of galvanized sheet-metal ducts into the various rooms of the building. In general, the warm air is admitted at or near the floor line and the foul air is drawn out by suction fans at or near the ceilings of the rooms. The design of the building is such that the heating stacks may be located in places where they occupy little valuable space, and the heating ducts are in most cases run in the ceilings of the rooms and passageways. Fig. 2, Plate LXXXVI, shows a typical portion of the piping and hot air duct system in the Station.

The total volume to be heated in the building is 10 280 000 cu. ft., and it was estimated that to provide proper heating and ventilation under maximum conditions would require the circulation of 2 000 000 lb. of water per hour at a temperature of 200° Fahr. with a return temperature of 160 degrees. The fans (Fig. 1, Plate LXXXVII) and local stacks (Fig. 2, Plate LXXXVII) used for transferring this heat have a capacity of 37 000 000 cu. ft. of air per hour raised from zero to 130° Fahr., requiring about 77 000 000 thermal units.

The total loss for exposure, with the outside temperature at zero and the inside temperature at 70° Fahr., is about 30 000 000 B. t. u. per hour, and the air entering the rooms at such times is heated to about 120° Fahr., with a discharge velocity of about 300 ft. per min.; an average drop of 10° is allowed for losses in the air ducts.

The heating surface in the nine heating chambers aggregates 76 500 sq. ft., made up of cast-iron cellular units in fifteen different stacks. Each of these stacks is provided with a motor-driven fan,

the motor being belted to the fan pulleys, so that the fans may be driven either by single motors or in groups. The fans are multi-vane, and the motors are of the three-phase induction type, varying in horse-power from 20 to 40. The fan capacities vary from 15 000 to 75 000 cu. ft. of air per min. Screens are provided in the fan chambers for cleaning the air.

Ventilating System.—Galvanized-iron ducts and exhaust fans are provided for ventilating purposes in addition to the heating fans. There are twenty-one different fans for the purpose, varying in capacity from 4 300 to 32 000 cu. ft. of air per min., with belted motors varying in capacity from 2 to 10 h.p. The total capacity of these ventilating fans is 43 000 000 cu. ft. of air per hour, or sufficient to change the air in the different sections of the building from three to ten times per hour, depending on the occupancy of the particular space.

As the rooms used for different purposes communicate with one another, it was necessary, in designing this heating and ventilating system, to provide for suitable differential pressures in the rooms, in order that odors should not be communicated from one room to that adjoining; this is especially necessary in the ventilation of the kitchen and serving-rooms and of the various toilet-rooms. The pressure in these rooms, therefore, is maintained below that of those adjoining, so that the ventilation is into them rather than the reverse. The ventilating system of flues and fans, therefore, is divided into two sections, giving entirely separate ventilation for the kitchens and toilet-rooms. Ventilation of the toilet fixtures is accomplished with a local vent in a closed space back of each fixture, which in turn is connected to an exhaust vent, so that, in operation, a current of air is continually drawn into the toilet-rooms, passed through the fixtures, and discharged above the roof of the building.

In order to economize in the amount of heat required in the large public rooms in very cold weather, arrangements have been made to by-pass the discharge from the ventilating fans, either in part or entirely to the outside atmosphere, or to the heating stack chambers; thus the warmed air from the rooms may be used again in any proportion desired. The number of separate register openings required throughout the building to control the inlet and egress of air for heating and ventilating is 3 000.

Plumbing.—The plumbing comprises the extensive system of piping

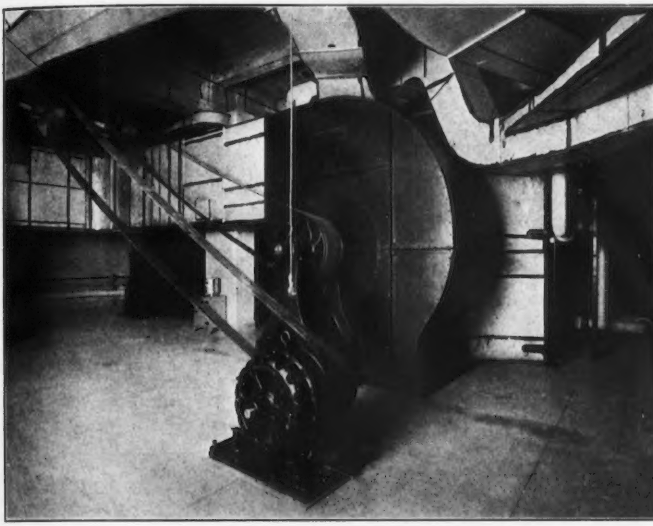


FIG. 1.—HOT-AIR FAN-ROOM IN STATION.

FIG. 2.—STATION HEATING STACK DURING CONSTRUCTION.

and apparatus for toilet-rooms and lavatories throughout the Station Building and yard. In the various terminal buildings, exclusive of those in the Post Office, 58 separate toilets have been installed. About one-third of these discharge directly into the sewers, and the remaining ones through ejectors. The capacity of the various toilets was determined by careful study of established practice for office buildings and public places. In the rooms of the Station alone, 846 fixtures have been provided, and a total of 932 throughout the entire area.

The main public toilets are noticeable for their size and completeness of arrangement. They are located immediately under the sub-waiting-rooms, on the level of the exit concourse, and are accessible by lobbies from the sub-waiting-rooms, and directly from the exit concourse. The men's toilet consists of a free room containing 51 closets, 71 urinals, and 35 wash-basins, and a pay toilet with 29 closets and basins in separate enclosures. The women's toilet is similarly arranged, and contains 100 free closets and 33 wash-basins, and a pay toilet of 44 compartments having toilets and lavatories. The interior of these rooms is finished with marble floors and Carrara glass side-walls and partitions between fixtures.

All piping has been placed in galleries or compartments behind the fixtures, and all pipes are exposed for inspection and repair. This arrangement is somewhat unusual because of the limited vertical height between the floors of the waiting-rooms and the clearance over the track level, requiring that the fixtures have side outlets.

Water supply for the toilets is obtained from the pumps in the Service Plant; the flushing water is the waste from the jackets of the compressors and refrigerating plant. More than 51 miles of piping were used in the runs to the various plumbing fixtures.

The toilet-rooms which have their waste at a level below that of the city sewers in the adjoining streets and avenues required a special system for elevating and discharging the waste to the level of the sewers. The ejectors designed for this purpose use air at a pressure of from 25 to 30 lb. per sq. in., operating automatically. They are located at twenty-two central points in niches in the subways under the tracks. Fourteen of the ejectors have a capacity of 50 gal. and eight of 100 gal. per min. Separate lines of pipe supply air from the compressors in the Service Plant to storage tanks near each group of ejectors; at these points reducing valves are placed to give the 30-lb.

pressure required. Pipes from the ejectors are run through the subways to the nearest convenient points adjacent to columns of the building and viaducts, up which they are run to the street connections; the lift is generally from 40 to 70 ft.

Cooled Drinking Water.—Pure drinking water of uniform temperature is distributed throughout the building by a separate system of piping. There are 158 special drinking fountains in the public rooms, the restaurant, and the office corridors. Water from the city mains is delivered to the Service Plant in 31st Street, where it is filtered, cooled to 40° Fahr., and pumped to the fountains. In the public rooms the fountains are supplied with vending machines which dispense paraffined-paper drinking cups at 1 cent each.

Pipe Gallery.—In connection with the description of the various piping systems, reference has been made to the difficulty of finding proper space for the pipes and heating ducts in a building which has no cellar or basement; many of these pipes are of large size, and should be located where they can be inspected from time to time. The problem was finally solved by constructing in the floor truss system, under the main waiting-rooms and the baggage-rooms, a pipe gallery having an extent of about 2 acres. This space is T-shaped, and of a height varying from 5 to 7 ft.; it is intersected by numerous trusses and lattice bracing, but is sufficiently open to permit of installing a large part of all the piping needed for the building services above, as well as heating ducts for the public rooms above. It communicates directly with the pipe gallery under 31st Street leading to the Service Plant. From this gallery a number of the vertical pipe shafts, leading up into the building, are reached, so that the main runs of pipe are everywhere accessible. All steelwork in the gallery is fire-proofed by encasing in cement, according to the Regulations of the City Building Department.

Fire Protection.—The fire protection of the building is described in connection with the general system under the heading, "Station Yard."

Watchmen's Registers.—Watchmen patrol the building hourly, and each carries a time register consisting of a "Newman" portable registering clock. He is required to record the time at stations by inserting in the clock a key kept in a special box at each station. There are key boxes at thirty-eight points in the building, and they are placed

so as to require the watchman to pass through all important sections in making a round.

Restaurant.—The dining- and lunch-rooms each have a serving-room attached, with a kitchen, store-rooms, refrigerator-rooms, offices, and help quarters above. All these are thoroughly appointed with most modern apparatus throughout. The seating capacity of the dining-room is 500 persons, at 125 tables; of the lunch-room, 40 tables, or 160 persons, and 93 stools at the counters.

The refrigerator contract called for the installation of forty cold-storage rooms, the largest of which is 34 by 42 ft., containing about 12 000 cu. ft. The insulation is of compressed sheet-cork of the best grade; the inside walls are of Carrara glass, and the floors are of tile. The boxes are cooled by overhead brine pipes, receiving circulation from the refrigerating machines in the Service Plant. The temperatures in these boxes vary from 8 to 38° Fahr., according to the purpose served.

The kitchen contains twelve roasting ovens, three charcoal broilers, and three gas broilers, all erected under a hood 54 ft. long. The pastry-room contains a gas range with ten ovens. The miscellaneous equipment includes electrical apparatus for meat-chopper, potato-parers, knife-cleaners, etc., and the service-rooms have electrically-operated dish-washing machines, steam-tables, etc., etc.

Offices.—The Eighth Avenue front of the building, and eastward on the side streets to the concourse, contains the office section, on three floors. The first floor is devoted to the Depot Master and train staff, with locker-rooms, a hospital, a police department, and funeral-rooms. The second floor contains the offices of the Division Superintendent and staff; the third floor contains the General Offices of the Long Island Railroad, and of the President and staff. On the Seventh Avenue side there are two floors of offices, at present not fully assigned.

Employees' Conveniences.—In addition to the above, the fourth floor, on Eighth Avenue and Thirty-first Street, has been fitted up for the housing and recreation of employees. The Thirty-first Street side contains sleeping-rooms, toilet and bathing facilities; the present capacity is 175 beds. The entire Eighth Avenue front has been fitted up for a Young Men's Christian Association, with an assembly hall, lecture-rooms, library and reading-room, billiard-room, bowling-alley,

and gymnasium; there is also a large lavatory with shower-baths, and a locker-room. All the above have been completely furnished.

Various small buildings, listed elsewhere, have been provided at the track level, under the Station and in the yard, for toilets, locker- and waiting-rooms, for employees on and off duty, or awaiting trains.

Post Office Building.

The change in destination of all through trains of the Pennsylvania system from the Jersey City to the up-town New York terminal required a revision in existing facilities for handling mails, of which about 250 tons are cared for daily. Anticipating the growing importance of an up-town central distributing Post Office, the United States Government purchased from the Railroad Company a plot of about 400 by 400 ft., immediately west of Eighth Avenue, comprising a portion of the Station yard, as a site for a suitable building. In the deed, the Railroad Company reserved the right of easement for their uses of all space below a plane substantially 20 ft. above the yard track level. In conveying the property to the Government, certain necessary agreements were entered into regarding the character of the building, the location of the supporting columns and foundations, and provision for open spaces around the building to admit of light to the tracks underneath. Pursuant to this deed, the Government has planned and is erecting an extensive and monumental building, and, while the Railroad Company is not responsible for the design of the building proper, the necessities of the yard construction work required that the foundations should be put in prior to the time when the building contracts were ready to be let, and simultaneously with the great variety of substructure work in the yard. It was arranged, therefore, that the Railroad Company, in conference with the Architects of the building, should plan and construct these foundations for the Government.

Design.—The following description of the architectural motif of this fine building has been furnished by Messrs. McKim, Mead and White, the Architects, and will be of interest in connection with the history of the general terminal facilities.

"The architects have endeavored, while keeping in mind the practical uses of the building, to give it the monumental character which a Government building of such importance should possess. In general, it may be said that as any building of modern height in New

York is likely to be of an inferior height to those eventually around it, the chance to compete with them will depend largely upon the great scale and unity of its design. For this reason the exterior was planned with as few breaks as possible in its façades, and a columnar motif running through two stories was adopted.

"In determining the character of the building, due consideration was given to the proximity of the Pennsylvania Station, and, in order that it might be in harmony with that building, the style adopted was Roman, and at the same time it was considered that the building must have a quality of its own which would associate it distinctly with the Governmental class of building. Rarely has so favorable an opportunity been presented for producing, on a scale commensurate with the Fora of Rome, such a development of colonnaded and pilastered façades complementary to each other and lending themselves to that unity of scale and style productive of the greatest effect.

"As a matter of composition, the Railroad Station having three pavilions, a building opposite to it, and shorter, with the same number of pavilions, would be an impossibility, and therefore the design was studied with the view to avoid a conflict of central motives; and for this, among other reasons, the design of the Eighth Avenue façade of the Post Office shows two pavilions joined by an unbroken row of columns of the same diameter as those of the Station, an arrangement which brings the two buildings into proper relation, produces the greatest possible effect in the given space, and which is, moreover, an expression of its plan.

"The principal approach to the building on the Eighth Avenue front is by granite steps the entire length of the colonnade, and subordinate approaches are also arranged for by means of granite steps giving access to the north and south fronts of the corner pavilions.

"The façades on the streets are continuous and of the same general motif as the Eighth Avenue front, pilasters being used instead of columns. The street façades are also terminated in pavilions at the westerly ends. The architectural style selected is Roman-Corinthian, that of the Station being Roman-Doric. The exterior material is granite.

"On the ground floor of the building the space allotted to the public is in the form of a wide corridor extending back of and on a line with the colonnade above referred to, back of which corridor is the general working space for distribution, handling of mails, etc., and on the westerly front of the building is a private driveway, connecting 31st and 33d Streets, by which access to the building is given to mail wagons and other city deliveries.

"Directly over the corridor on the Eighth Avenue front on the second-floor level, and in the center of the façade, is located the Postmaster's suite of rooms, and on either side and extending somewhat

back on the north and south fronts are located the rooms of his principal assistants.

"A mezzanine floor, between the first and second floors, and which is wholly back of the public corridor above referred to, is assigned chiefly to swing-rooms, locker-rooms, toilet facilities in connection with both of above, and for record- and document-rooms.

"The Eighth Avenue front of the third story of the building is assigned to the use of the Executive Staff of the Railway Mail Service; other parts of the second, third, and attic stories of the building are assigned generally to the working force of the various departments.

"The westerly and southerly portions of the basement of the building are assigned to the working force of the Railway Mail Service, and direct communication between this service and the Railroad Company's tracks and platforms, and between this service and the working space for mails on the floor above, is had by means of mail conveyors, elevators, chutes, and other mechanical installations. Other portions of the basement are assigned to newspaper and parcel distribution, mail sack storage and repairs, cashier's stock, etc."

The work for which the Railroad Company is responsible in connection with the Post Office, is the location of the building columns in relation to the tracks and platforms, the planning and constructing of the roofs for the light areas between the building and the street viaducts, and the provision for handling mail between the delivery floors in the building and the cars beneath.

Building Columns.—The columns have been laid out on substantially the same plan and spacing as adopted for the supports of the Station, for a building of approximately the same general height and loading. There are 200 columns in the platforms and between the tracks. The foundations for these columns are of concrete, to the level of the capstones or grillage, constructed by the Railroad Company as a part of its substructure work.

Connecting Roofs.—The connecting roofs consist of a permanent vault-light covering for the areas between three sides of the building and the adjoining street viaducts. The construction takes the form of a generally flat roof of I-beams carrying glass vault lights set in concrete. They are of the usual sidewalk-light type, and give about 40% of the total for glass area. The roofs are set at an elevation of about 6 ft. below the sidewalk level, and are designed to sustain a load of 100 lb. per sq. ft. The roofs have sufficient slope to drain to points 50 ft. apart, from which the drainage is piped to the yard system.

Mail-Handling Methods.—At present about 40% of the entire amount of mail originating in New York for outside points is received and dispatched by the Pennsylvania Railroad. On the heaviest days from 220 to 260 tons are carried in from 12 000 to 16 000 pouches, each weighing about 200 lb. The great bulk of this mail, about 80%, has been heretofore delivered at Jersey City by wagons directly into postal or mail storage cars on side-tracks adjoining the station and convenient for the teaming yard; these cars frequently lie on the tracks several hours while loading and unloading.

Practically all this mail, in addition to that from the Long Island Railroad, and, at a later date, possibly, from the New Haven Road, must be provided for at the new Station, under physical conditions radically different from those existing at Jersey City. The new Post Office Building being over the railroad yard, it is obvious that unlimited track space for standing mail cars, or platform space for loading mail into the cars, cannot be provided; in fact, the value of each foot of space in the yard is so great that provision must be made to handle the mail in the most expeditious manner, and on very limited track room.

The track space assigned especially for standing mail cars is centrally located in the yard, partly under and partly west of the Post Office Building, and consists of six tracks, adjoining four of the central platforms, having a total maximum storage capacity of twenty-six postal cars. Numerous plans were considered by the Joint Committees of Postal and Railway officials for the utilization of the available track and platform space, in order to load and unload the cars in the shortest possible time and with least manual effort, and it was thought essential to develop a complete system of mail-handling machinery, consisting of chutes and horizontal conveyors for outgoing mail, and horizontal conveyors and bucket lifts for incoming mail, together with vertical lifts for mail on trucks. This system is designed to reach, not only the Post Office Building, but, through the trucking subways under the tracks, any part of the main Station Building, and provides for the mechanical handling of all bulk mail for railway post office or storage cars, and the convenient trucking and elevating of sacks to and from combination cars standing at any station platform. In general, the system may be described as follows:

Incoming Mail.—Mail in less than car-load lots, or in combination cars, will be unloaded as the train stands in the Station, on trucks, and conveyed to the Post Office either along the platforms or, by utilizing the nearest baggage lift, descending to the trucking subway under the tracks, and thence to the Post Office lifts. In the case of car-load lots and bulk mail, the cars will be switched to the tracks adjoining platform No. 4, where the mail will be unloaded manually and dumped into hoppers on the platform. From these hoppers the mail pouches will be pushed automatically by compressed-air rams on a belt conveyor located under the platforms; this belt will convey the bags to a point where a tilting tray operates to transfer them automatically to a vertical bucket lift, which will elevate them into the Post Office mezzanine floor, from which they will be delivered through spiral chutes, and, at the option of the employees, either to the receiving mail platform on the first floor or to the basement of the building.

The compressed-air rams, for charging the pouches from the chutes to the belt conveyors, consist of a pair of tandem cylinders and pistons of different diameters fastened to one piston rod, for the purpose of getting a differential effect; reciprocating action is secured by different pressures obtained through two lines of piping, one supplying and maintaining a constant pressure between the two pistons and the other supplying a variable pressure applied to the outer end of the larger piston. The necessary timing effect is secured by a group of ram-operating valves with cams driven mechanically by a shaft from the bucket-lift mechanism. Thus the ram pushers will deliver the pouches to the belt at the proper intervals to be taken by the lift buckets when unloaded there. Co-ordination between the movement of the rams, the loading trays, the conveyors, and the lifts, is further secured by centering the motive power in one electric motor.

Outgoing Mail.—Mail in less than car-load lots will be handled directly into the cars by manual unloading from automobile trucks; these may reach the cars through the trucking subway and baggage lifts, or along the platforms from the Post Office lifts. Bulk and car-load mail, however, will be delivered into the cars automatically from the Post Office floors, as follows: The four central platforms, before referred to, adjoining the six car-storage tracks, are provided overhead with horizontal belt conveyors; these conveyors are placed in housings attached to the framework of the building, and west of it, in special

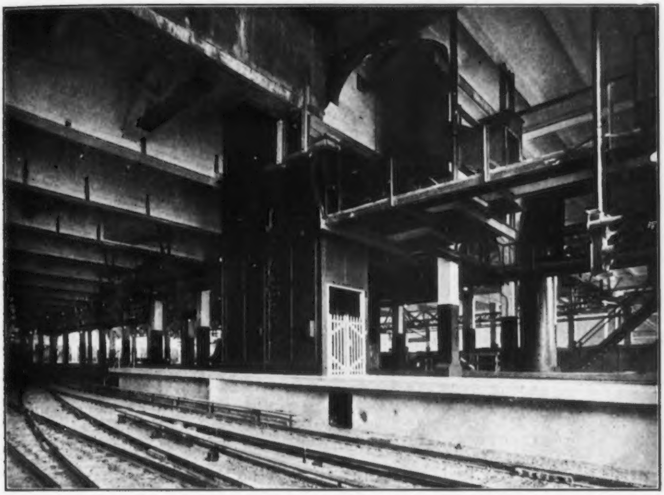


FIG. 1.—MAIL-HANDLING MACHINERY UNDER POST OFFICE.

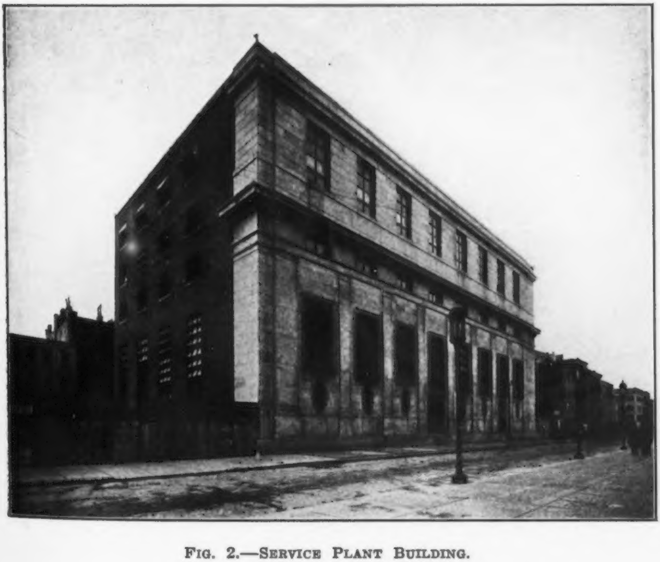


FIG. 2.—SERVICE PLANT BUILDING.

structures carried by columns set in the platforms. The conveyor belts are driven by electric motors at a speed of about 100 ft. per min., and included in their paths are self-propelled carriages operating as "trippers" and running on tracks in the housings. These carriages may be run automatically to any desired position opposite the mail-car doors and operate to trip the mail pouch into a spout attached to the carriage and thence into the car door.

Mail from the working floor of the building is delivered to the belt conveyors through spiral chutes, single, double, triple, or quadruple, as occasion requires, for simultaneous delivery from the various building floors and to either of the two conveyors east and west on each platform. Fig. 1, Plate LXXXVIII, is a view of the mail-handling machinery under the Post Office.

In addition to the conveyor system as described, there are four hydraulic lifts, of the plunger type, affording trucking communication between the building, the platforms, and the subways.

All the foregoing mail-handling facilities were provided by and will be operated by the Railroad Company. The special conveyor machinery was designed by Messrs. Marks and Woodwell, Consulting Engineers for the Architects of the Post Office, and was installed by the Lamson Belt Conveyor Company. The work was administered and co-ordinated in the usual manner through the office of the Chief Engineer of the Railroad Company.

Express Building.

The terminal operation does not at the present time include facilities for the handling of express freight matter; this class of business, for the time being, at least, will be cared for at the Jersey City Station of the Pennsylvania Railroad, and at Long Island City for the Long Island Railroad, as heretofore. To provide for the possible future handling of Express Company's freight at the new terminal, a location was set aside for an Express Building at the west side of Ninth Avenue, adjoining 31st Street. The area required by the building was excavated as part of the terminal yard, and, pending the erection of the building, will be used for a general storage yard. The area will admit of a building 130 by 180 ft., and the yard space under it will provide for one wide loading platform with a track at each side, accommodating a total of 12 express cars, with two additional

platforms in the yard between Eighth and Ninth Avenues, accommodating 24 cars. The total storage and loading capacity of the express yard tracks is 55 cars.

The express platforms will be reached from the building by hydraulic lifts, communicating with the main platform under it, and thence to the trucking subway system under the tracks and up to the other two platforms, and if desired, continuing through the subway to the main Station Building.

Service Power Plant.

Aside from the traction requirements, there are numerous and important uses of power in various forms in a large Station, namely:

(*a*) Heating and lighting the Station and other buildings;
(*b*) Steam, compressed air, and water supply for cars;
(*c*) Air supply for the signal system, for tunnel drainage pumping, and for sewage ejectors;
(*d*) Water supply for various purposes in the buildings, and for fire protection;
(*e*) Hydraulic power for elevators and lifts;
(*f*) Refrigeration for cold boxes in kitchens and restaurants, and for drinking water;
(*g*) Electric power for lighting buildings, tunnels, and yards; stationary motors for elevators, heating and ventilating fans in building and tunnels; motors for pumping in yard and tunnels; power for car battery charging, operation of telephones, clock system, and other minor uses;
(*h*) Traction power for moving trains.

Building.—The proper housing of all these important facilities required a large amount of space. The character and location of the Station precluded their installation in that building, and no central space for a special building was available in the yard without sacrifice of valuable track room. Fortunately, a convenient location was available on relatively cheap property of the Company on the south side of 31st Street, about midway between Eighth and Seventh Avenues, and directly accessible, under 31st Street, from the Station and yard. The building erected on the plot has a frontage of 160 ft., a depth of 95 ft. and a height of 86 ft. above the curb, with a depth of 49 ft. below. The building (Fig. 2, Plate LXXXVIII) was designed of a height and character to harmonize with the Station Building, with an endeavor to maintain the standards of the Station in all Company construc-

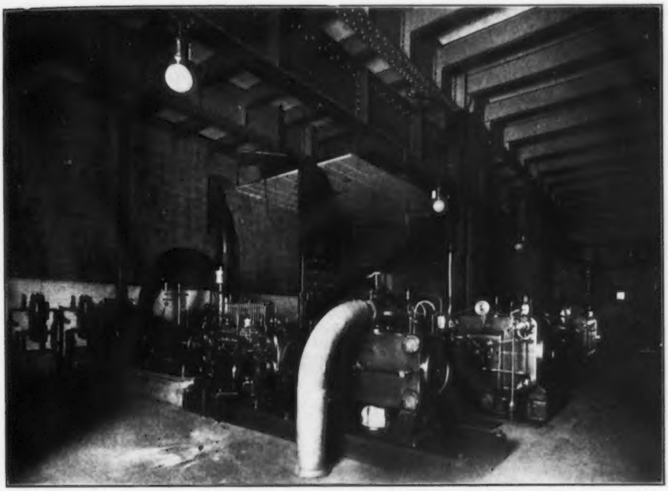


FIG. 1.—MAIN AIR COMPRESSORS IN SERVICE PLANT.

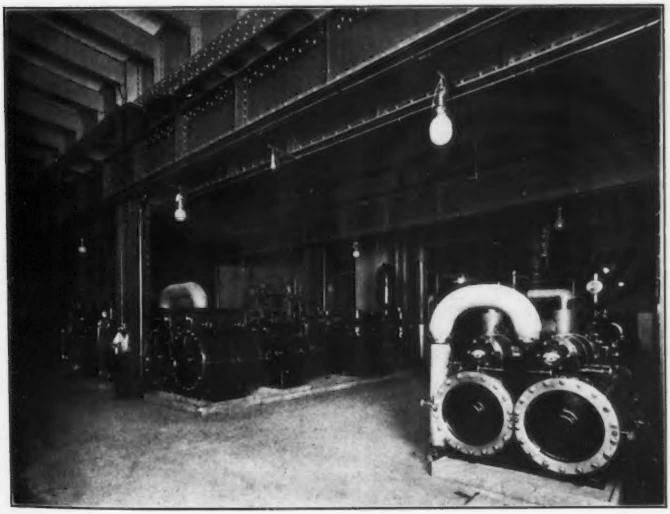


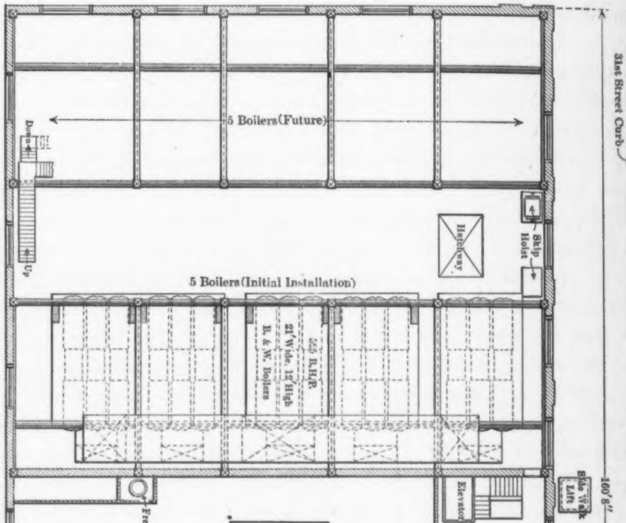
FIG. 2.—HYDRAULIC ELEVATOR PUMPS.

tions. The façade was designed by Messrs. McKim, Mead and White, and is of Stony Creek pink granite, similar in effect to that used for the Station exterior. The building construction is fire-proof throughout, having steel framing, masonry walls, and concrete floors and roof. The machinery on the various floors, and the coal storage and stacks required very heavy framing, 2 500 tons of steel having been used in the structure. The general plan, as shown by the drawings (see Fig. 7), divides the building by a fire-wall vertically into two main parts, the west half being devoted to the machinery and boiler plant, and the east to the traction sub-station, offices, and store-rooms.

The basement, which is at the level of the sub-grade below the tracks, contains the foundations for machinery, the engine piping, garbage destructor, cable-splicing chambers, and the main entrance to the pipe and trucking subways under the yard. The engine-room on the floor above (see Fig. 8) contains the lighting generators, the air compressors, the hydraulic power pumps, refrigerating engines and apparatus, and the heaters and circulating pumps for the Station. The third floor contains the fire and boiler pumps, water-storage tanks, and a pipe gallery to the Station Building. The next, or street floor, contains the boiler-room, above which are floors for coal storage, and economizer-rooms. A brick stack terminates above the roof. Plate LXXXIX shows the main air compressors and the hydraulic elevator pumps.

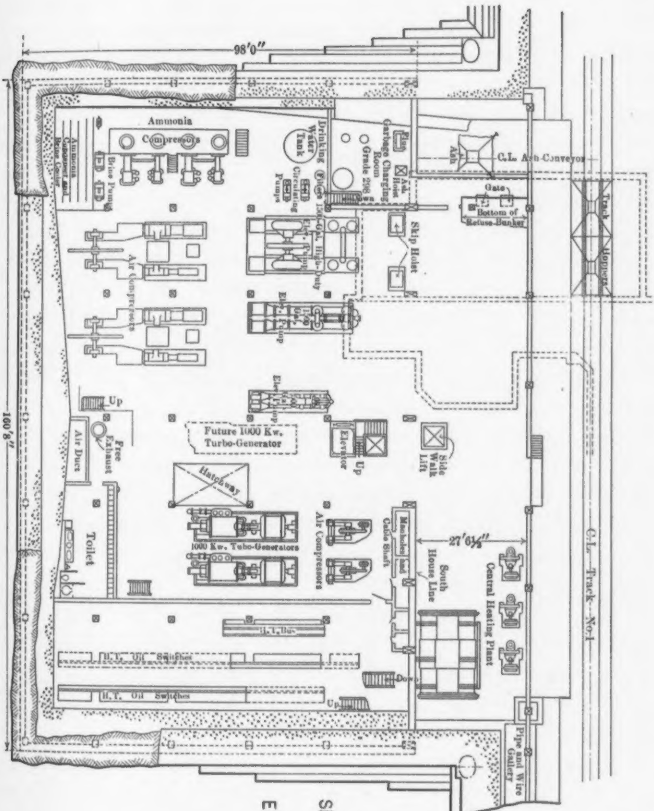
The east half of the building (see Plate XC) contains the traction sub-station, and has three floors below the street, for the cable inlets, bus-bar structures, and switching apparatus, and a main street-level floor for the rotary and switch-board room (see Fig. 1, Plate XCI). Two store-room floors are above this, and the top floor is fitted up for offices to be used by a portion of the operating staff.

Boilers.—Space has been provided for ten 525-h.p. water-tube boilers arranged in two rows of five. Each row is provided with an independent draft system, smoke-flue, economizers, and stack. The initial installation consists of five of these boilers on the east side of the room; this equipment is sufficient to provide for the heating load of the buildings erected up to the present time, and of the yard, on the basis of an estimated load of 2 500 b.h.p. in the coldest day of the winter. When the proposed express and other buildings around the yard are erected, additional boilers will be installed as required.



PLAN OF BOILER-ROOM AND SUBSTATION FLOOR, SERVICE PLANT

Fig. 7.



PLAN OF SERVICE PLANT AT ENGINE ROOM LEVEL

FIG. 8.

The boilers are arranged with shaking grates, for hand-firing with small sizes of anthracite coal. Draft is produced by a short stack supplemented with forced draft under the grates, furnished by fans of the Sirocco type, with 70-in. wheels, direct-connected to steam engines. The stack is of brick from its base at the roof of the building, and is carried on steel framing from the basement. It has an inside diameter of 11 ft., and is at present 50 ft. in height above the roof, or 127 ft. above the grates. If tall buildings at some future time adjoin the power-plant, the supports will admit of carrying the stack 150 ft. above the roof.

The ashes from the boilers are dumped into concrete-lined hoppers, arranged with the necessary gates to discharge into hopper cars which are moved on tracks to an ash-storage bunker of 80 tons capacity under the 31st Street sidewalk. From this bunker the ashes are carried by a belt-driven conveyor to railway cars standing on the southernmost track of the terminal. The conveyor is arranged so that it may be extended over the car when in use.

Coal is delivered by car to the track in front of the Service Plant, is dropped into a hopper under the track, and elevated by a belt conveyor discharging into feeding hoppers in the basement; from these it is hoisted in skips and discharged into the coal bunker by belts. This bunker is above the boilers, and has a storage capacity of 1 000 tons, or about one week's supply.

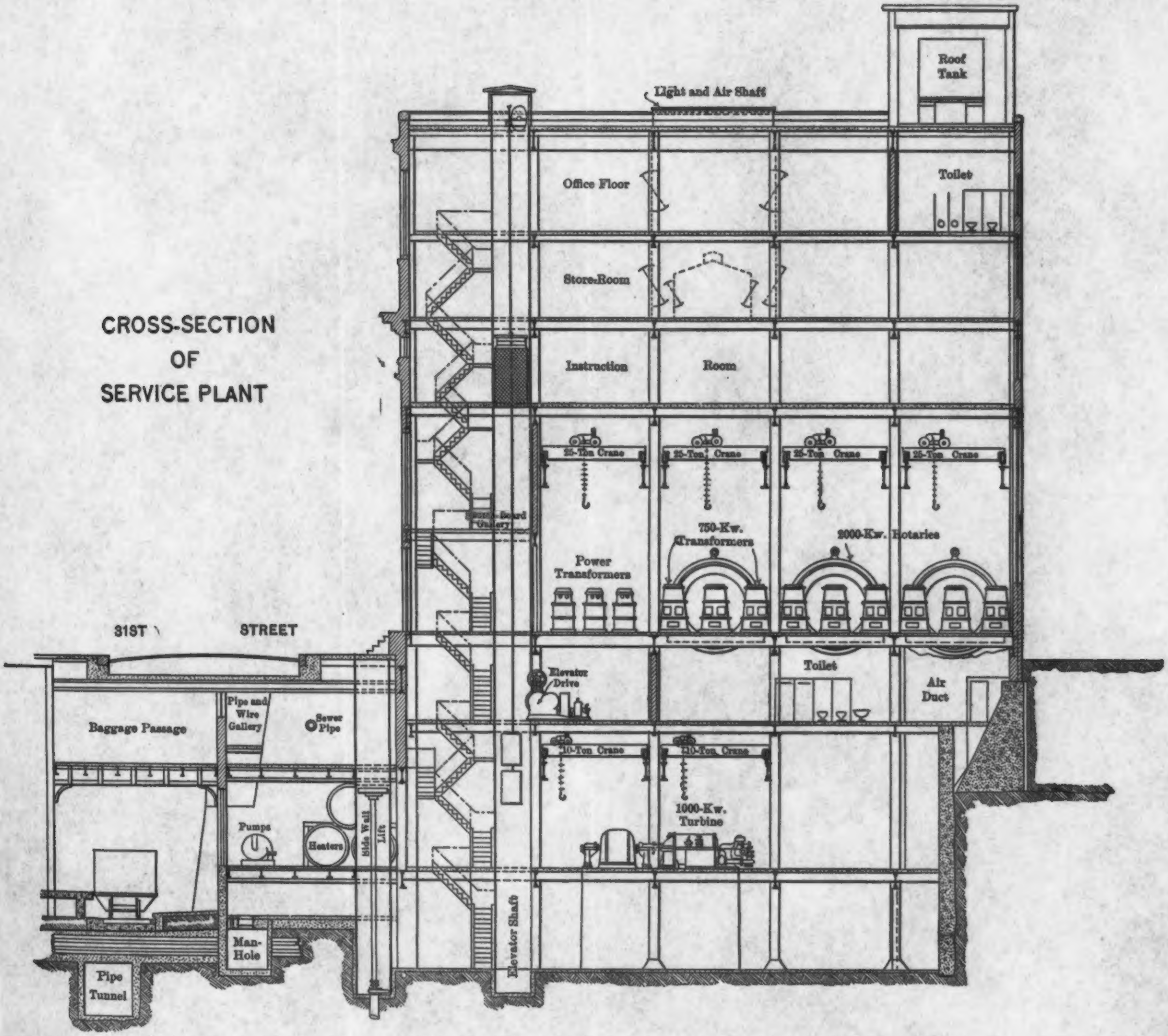
Two economizers, each of 320 tubes capacity, are provided for each row of five boilers, and located above the boiler-room. The boiler feed-pumps are of the compound duplex type, each pump having sufficient capacity to take care of the entire load under maximum conditions.

Water Supply.—Water for all purposes in the Service Plant, Station, and yard, is obtained from one public and one private 12-in. main in 31st Street, connected to independent city mains at Seventh and Ninth Avenues, respectively. The water is metered at the building and distributed through piping systems, as later indicated. As an emergency supply in case of a complete shut down of the city mains for a considerable period, five storage tanks, having a combined capacity of 75 000 gal., have been installed. The water system provides for:

(1) Boiler feed;
(2) Fire protection;

PLATE XC.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1165.
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.

CROSS-SECTION
OF
SERVICE PLANT



(3) Fresh water for the general services in connection with kitchens and restaurant, and for lavatory purposes;
(4) Water for cooling air-compressor jackets; inter-coolers and after-coolers for the ammonia condensers, which is afterward used for flushing toilets;
(5) Water for general yard purposes, such as car cleaning.

Water for all purposes is drawn from the mains and storage tanks by the pumps listed under the plant apparatus. There are two fire pumps, of the "Underwriters'" pattern, and they are kept constantly under steam, working slowly through regulators set to maintain a constant pressure of 90 lb. per sq. in., and drawn from to a limited extent for yard purposes. They are cross-connected to work singly or in battery.

For house-service purposes there are three motor-driven centrifugal pumps, having a capacity of 300 gal. per min. One of these pumps is used for flushing-water for the toilet fixtures in the Station, and obtains its supply from the cooling water of the refrigerating plant and air compressors, which delivers into a 5 000-gal. storage tank on the roof of the Service Plant. One pump is used for pumping fresh water into a second 5 000-gal. storage tank on the roof, and furnishes fresh water for various purposes in the Station, for which the cooling water used for flushing would not be suitable, such as for kitchen and restaurant purposes. This pump delivers into two 1 500-gal. tanks on the roof of the Station Building over the kitchens. The third pump is a spare one for both systems.

For operating the hydraulic elevators and lifts in the Station and Post Office Buildings, three pumps have been provided; one 1 500-gal. high-duty, crank-and-fly-wheel pump, one 1 500-gal. compound, duplex, direct-acting, and one 500-gal. compound, duplex, direct-acting. These pumps are shown on Fig. 2, Plate LXXXIX. These sizes were selected after a study of the operating conditions during the busy-hour schedule, the maximum estimated quantity of water required at such time being 2 000 gal. per min. This requirement is met by operating one of the large pumps and the small one. During the winter, when exhaust steam is needed for heating, the direct-acting pump will generally be used, the high-duty pump being used when the demand for exhaust steam is light. These pumps operate at a steam pressure of 150 lb., against a back-pressure of 2 lb. from the exhaust, and furnish water at 300 lb. gauge pressure with a back-water pressure of 40 lb.

The heating system for the Station Building, elsewhere described, requires heaters for the water, and pumps for circulating the hot water. There are three heaters in the Service Plant. They are steel drums, ½-in. thick, 5 ft. 7 in. in diameter and 23 ft. long. Each contains 557 2-in. wrought-iron tubes, giving 5 830 sq. ft. of heating surface. Steam passes through these tubes, and the water circulates around them, with suitable baffle-plates to secure the maximum efficiency of the heating surface. Each heater is piped to a water-circulating pump of the centrifugal type, direct-driven by 50-h.p. induction motors.

Air Compressors.—Compressed air is required for operating switches and signals, brake-testing in the yard, pumping in the tunnels, and for the sewage ejectors and the air cleaning machines. These various services were estimated to require a rated compressor capacity of 1 900 cu. ft. of free air per min. As exhaust steam is required for a large part of the year for the Station heating, it was found more economical to install steam- than motor-driven compressors. Therefore, two were provided, each capable of supplying the maximum total service demands. The machines are of the cross-compound, two-stage, Nordberg-Corliss-valve type, each having a capacity of 2 000 cu. ft. of free air per min., and compressing to 90 lb. per sq. in. The compressed air is passed through an atmospheric after-cooler, located on the roof of the building. In order, however, to provide for the higher pressure required for testing air brakes on cars, there is a separate compressor plant consisting of two two-stage, two-cylinder machines, each having a capacity of 100 cu. ft., and driven through link belts by 30-h.p. induction motors. These compressors deliver air at a pressure of 125 lb. per sq. in. to a separate piping system in the yard.

Refrigerating Plant.—Refrigeration is required for the cold boxes in the kitchen and dining-room department of the Station, and for cooling drinking water for fountains in various public rooms and corridors. The maximum requirements for all these purposes is equivalent to the melting of 56 tons of ice per day during the summer, or an average of 40 tons throughout the year.

Much consideration was given to the question of the most convenient and economical means of providing the required refrigeration for all terminal railroad purposes. The cooling of stationary boxes by ice would require the regular delivery of large quantities of ice to a great number of separate places, at considerable inconvenience, and

FIG. 1.—SWITCH-BOARD ROOM IN SUB-STATION, 31ST STREET SERVICE POWER PLANT.

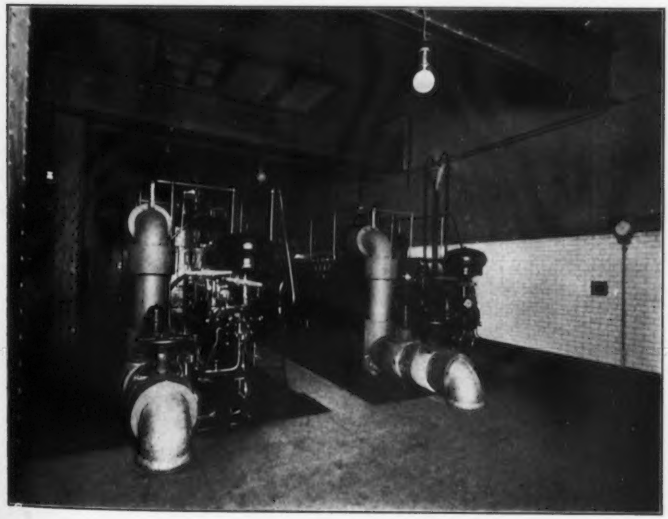


FIG. 2.—STEAM TURBO-GENERATOR IN SERVICE PLANT.

it was calculated that a refrigerating plant would furnish the requirements at a lower cost, when installed in the Service Plant, together with the other facilities of that building. Ice, however, must be supplied in limited quantities for the cars and for drinking-water in the restaurant. For these latter purposes it was thought best to bring ice in cars through the tunnels, and deliver directly from the car in the yard, or from an ice-storage room provided in the Service Plant.

For the general refrigeration, however, a complete plant was installed, consisting of two units each of 40 tons capacity, one unit being generally available as spare. These circulate cooled brine through a piping system to the Station Building. The temperatures required in the cooling boxes throughout the building vary from a minimum of 8° Fahr. in the ice-cream box, to 38° Fahr. in the meat boxes. In order that the above temperatures may be obtained at the boxes, the outgoing brine from the refrigerating system must leave the coolers at a temperature as low as from zero to 15 degrees. Three brine-circulating pumps have been installed, one of which is used for the ice-cream boxes, one for the meat boxes, and the third is a spare one for either system. In order to utilize the available floor space, vertical compressors were adopted, direct-driven by horizontal engines. They are single-acting, compression being accomplished during the upward stroke, and thus bringing only low evaporating ammonia pressure on the piston rod and piston packing, and minimizing the ammonia leakage. Each compressor is rated at 40 tons capacity on the basis of 185 lb. gauge, and an evaporating ammonia pressure of 15.67 lb. gauge. The engines have Corliss gear, operate at 76 rev. per min., and have a capacity of 70 i.h.p. The condensers are common to both the compressors, and are of about 50 tons capacity, with room to extend them later if found necessary. They are subdivided into sections, 12 pipes high, and are controlled by valves, to allow of convenient cleaning and repairs without interruption to the service. The interior arrangement consists of a horizontal, double-pipe system, made up of 2-in. outer pipes, carrying ammonia gas, and 1¼-in. inner pipes, carrying cooling water. The pipes are 20 ft. long, and their ends are joined by return bends and arranged for counter-current circulation of ammonia gas and water. The brine cooler consists of a nest of double piping similar in arrangement to the condenser. The outer pipes, which are 3 in. in diameter, contain the ammonia gas, and the 2-in. inner pipes, the brine circulation.

Drinking Water.—The apparatus comprising the drinking-water system is in the Service Plant, and consists of meters for measuring the water from the city mains, a filtering plant having a capacity of 400 gal. per hour; a cooling and storage tank having a capacity of 700 gal., operating in connection with the refrigerating plant described in the previous section, and two motor-driven, centrifugal pumps, delivering the cooled and filtered water to the special piping system for the fountains throughout the Station. The filtering is done alternately in two cast-iron, porcelain-lined drums, first through sand and then through charcoal. The current in these drums is reversed when required for cleaning. The water-cooling tank is of $\frac{1}{4}$-in. steel plate, enameled inside with glass enamel $\frac{1}{16}$ in. thick. The water is cooled in this tank by direct-expansion, ammonia-pipe coils, forming a part of the general refrigeration plant.

Garbage Destructor.—It was estimated that about 5 tons of wet kitchen garbage and the same quantity of dry refuse would accumulate in the terminal per day. Its prompt disposal was arranged for by the installation of an incinerating plant in the basement of the Service Building. This destructor is of the Morse-Boulger make, and consists of furnaces lined with fire-brick and containing four separate grates. In one of these the dry refuse (or coal) is used for fuel to supply heat for drying out and burning the wet refuse, and a second fuel grate is provided for an auxiliary fire to consume the gases from the offensive refuse. Two fire-brick grates, an upper and a lower, are used for wet garbage, which is dried and consumed by the heat from the fuel grates. The gases pass from the furnace to the main boilers and thence to the stack.

Garbage is brought from the kitchens in closed wagons to a cold room in the building, where it may remain until the furnace is ready for charging. It is then dumped on a tray on the floor above, sorted for valuable articles, such as silverware and linen, and then charged into the furnace through a grating at the top.

Lighting and Auxiliary Power Generators.—The approximate electric power requirements for all purposes (except for traction) are as follows:

Station lighting	600	kw.
Tunnel lighting	125	"
Motors for heating, ventilating, elevators, etc.	1 325	"
Motors for sump pumping	800	"

Motors for tunnel ventilation...............	350	kw.
Motors for Post Office mail-handling machinery	55	"
Power for signal system....................	175	"

All these various requirements might conceivably be met by the use of one source of electric power, and it would be possible to take the current from the main traction generators; but it can readily be seen that the services are so important that they cannot be considered as incidental, and therefore, the power system selected for them should not sacrifice perfect reliability and adaptability to the utmost degree of simplicity and economy in installation, or even of operation. The following considerations, therefore, were the guiding ones in designing this miscellaneous power system.

First.—It was determined to light the Station Building by small individual lights, rather than by powerful arc lamps; and, for reasons of economy, as elsewhere explained, it was decided to use Nernst lamps for the general lighting, a form of lamp requiring, for economy, alternating current at 240 volts.

Second.—The tunnels require to be lighted at all times by a system which is independent of the traction power, so that in case of failure of this latter, there will still be lights outside of the trains. The kind of current used for Station lighting will likewise be suitable for the same purpose in the tunnels.

Third.—Electric power is needed for operating the signal system, as elsewhere explained, and must, in part, be of the alternating-current type; the lighting generators, therefore, are suitable for the needed supply.

Fourth.—Alternating current may also be used for the various stationary motors, except that in case of the electric elevators, alternating-current motor control has not been as thoroughly perfected as in the case of direct-current control. Therefore, it was decided to operate all motors, except those for electric elevators, from the same alternating-current generators as were used for other miscellaneous power purposes. In order not to introduce another system of generation for electric current, it was decided to operate the elevators directly from the traction circuits at 650 volts.

Fifth.—For the minor purposes of car-battery charging, telephones, clocks, etc., small motor generators are used, converting the alternating into direct current of the required voltage.

The next consideration was that of properly safeguarding the generation of miscellaneous power, with due regard to economy in first cost and operation. As the Service Plant is essential for heating and other yard purposes, it seemed, logically, the proper one to furnish auxiliary electric power, as the exhaust steam from the engines could be utilized in cold weather to provide heat for the Station Building. As laid out, therefore, the miscellaneous electric power system consists of two independent sources of power generation, with duplicate machines at each source; and machines of the alternating-current type are used, permitting distribution to the various services at any desired voltages, through suitable transformers.

The following is a list of the various electric currents used for different miscellaneous power purposes, and produced at the Service Plant, except current for elevators, which is taken from the traction circuits; these are from one source, transformed and converted as required:

11 000-volt,	A.C.,	60-cycle...	High-tension service feeders.
2 200 "	"	"	Signal lines.
220 "	"	"	Signal lines in yard cabins.
650 "	D. C.	....	Third-rail feeders and office elevators.
420 "	A. C.,	60-cycle..	Motors.
240 "	"	" ..	Lights.
220 "	D. C.	....	Elevator control.
110 "	"	....	Car-battery charging and exciters.
35 "	"	....	Baggage-truck battery charging.

The machines installed to care for this general system consist of two 1 000-kw. turbo-generators. These supply, through step-up transformers, three-phase alternating current, at 11 000 volts and 60 cycles, to the service power switch-board. They operate non-condensing, the exhaust steam being passed through the heaters for the Station Building heating. At seasons when the exhaust cannot be utilized for this purpose, the machines are shut down, the power supply being taken from generators in the Long Island City Power-House, where condensing turbines of a more economical rating are available.

Traction Sub-Station.—The traction sub-station is described in full under the general power heading, and need only be referred to

FIG. 1.—REMOTE-CONTROL, TRACTION FEEDER, CIRCUIT-BREAKERS AND SWITCH PANELS, IN SERVICE PLANT SUB-STATION.

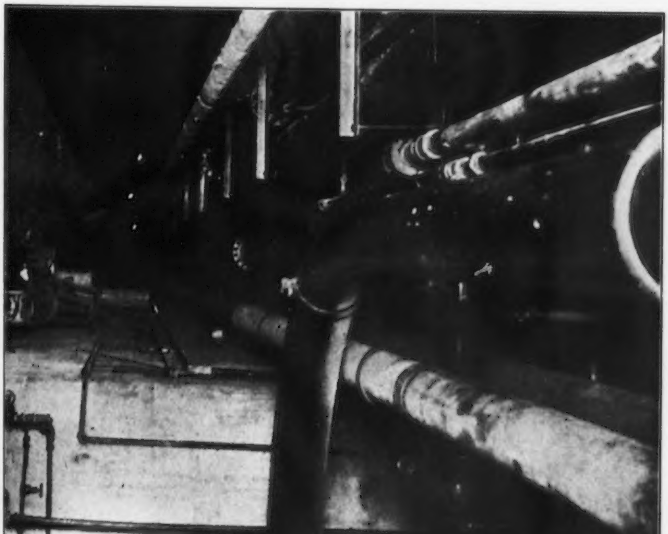


FIG. 2.—INTERIOR OF ONE OF THE PIPE SUBWAYS UNDER THE TRACKS.

here as consisting of the complete sub-station, occupying the east half of the Service Building.

Offices and Store-Rooms.—Above the main floor of the east half of the building are located the following:

(*a*) On a mezzanine floor overlooking the rotary-room, a space of 980 sq. ft., for locker-room and toilets, and offices for the service plant foreman and assistants;

(*b*) On the third floor an instruction-room and office, 6 200 sq. ft. in area, containing apparatus to illustrate the construction and methods of operation of the special devices of the signal system, electrical equipment of the division, etc. These include complete working parts of the devices in question, with sectional models showing their internal construction. The systems illustrated are:

Block and interlocking signals,
Automatic train stop,
Car and locomotive air brakes,
Electric control apparatus of locomotives and cars,
Tunnel alarm and telephone boxes,
Third-rail construction and switching apparatus,
Apparatus for testing sight and hearing.

(*c*) The fourth floor, an area of 6 200 sq. ft., has been fitted for a general store-room for supplies of all kinds;

(*d*) The fifth floor is subdivided into offices for certain of the division staff, the space for offices, excluding corridors, being 4 300 sq. ft.

The following is a concise statement of the Service Plant machinery equipment, excluding the traction sub-station equipment listed elsewhere:

Water-tube boilers, 525-h.p. each; ultimate capacity, ten boilers; pressure, 200 lb.	5
Single-acting, high-speed, steam engines, 50 h.p. each, driving Sirocco fans, for forced draft	2
Green fuel economizers	2
Water storage tanks; capacity 75 000 gal.	4
Coal conveyor, two pairs, capacity 120 tons per hour	4
Coal-skip hoist engine	1
Ash conveyor, 50 tons per hour, motor-driven, belted	1
Garbage destructor	1

Boiler feed-water heater; capacity, 6 500 gal. per hour from 70° to 200° Fahr.	1
Boiler feed-pumps, duplex-tandem, compound, steam-driven.	2
Hot-well pumps, centrifugal, motor-driven	2
1 000-k.w., 240-volt, 3-phase, 60-cycle, Westinghouse-Parsons, steam-driven, direct-connected turbo-generators. (Space for one additional)	2
2 000-cu. ft. per min., Nordberg, cross-compound, Corliss, steam-driven, air compressors, 100 lb. pressure, for signals and sewage ejectors	2
100-cu. ft., motor-driven, air compressors, 125 lb. pressure, for brake testing	2
Elevator pump, 1 500 gal. per min., 300 lb. pressure, steam-driven, for hydraulic baggage and passenger elevators	1
Elevator pump, 500 gal. per min., 300 lb. pressure, steam-driven, for hydraulic baggage and passenger elevators	1
Compound, steam-driven pump, 1 500 gal. per min., for baggage and passenger elevators	1
Steam-driven, Westinghouse, air-brake pumps, for elevator air cushion	2
Duplex, steam-driven, Underwriters' fire pumps, capacity, 1 500 gal. per min. each	2
Motor-driven, automatic, centrifugal pumps, for circulating cold water and water for flushing purposes	3
Motor-driven, centrifugal pumps, for hot-water circulation to Station indirect heating system	3
Heater for Station indirect heating system	3
Heater, 635 gal. per hour, for hot water in Service Plant	1
Refrigerating plant, 40-ton ammonia compressors, engine-driven.	2
Brine pumps, motor-driven, centrifugal	3
Motor-driven, 1½-in. centrifugal pumps for circulating drinking water	2
750-kw., single-phase, 60-cycle, 11 000-420-volt, air-blast transformers	3
500-kw., single-phase, 60-cycle, 11 000-246-volt, air-blast transformers	3
150-kw., 60-cycle, 11 000-2 200-volt, O.I.S.C. transformers for signals	2
100-kw., 60-cycle, 11 000-220-volt, O.I.S.C. transformers for signals	2
80-kw., 110-220-volt, motor-generator sets, for car-battery charging	2
40-kw., 110-volt, motor-driven exciters	2
25-kw., 35-volt, motor-generator sets, for baggage-truck charging.	2
55-cell storage battery, for emergency excitation	1

TUNNEL FACILITIES.

The extensive system of more than 15 miles of single-track tunnels has been fully described, as to physical construction, by others; the railroad and the operating facilities, however, will be referred to briefly.

Size of Tunnels.—The size of the tunnels was a consideration of great importance in the subaqueous tubes, where a determination of the minimum practical operating diameter was essential in order to avoid a large expenditure of money unnecessarily. In a tunnel of circular cross-section, the height from the invert to the crown of the arch is the controlling dimension, to accommodate the track structure and the cars. This height, therefore, was considered carefully by the Board of Engineers and the Committee of Operating Officers, having due regard to probable deviation from a true central axis in the process of tunnel-driving. A minimum was fixed for the depth of the ballasted form of track, and a minimum clearance over the top of the cars in which to provide for wrecking operations, and also for the possible use of an overhead electric conductor for traction, should this later be considered practicable and desirable at the time when the traction system was determined on, or even at a later date, should developments in the art require it. The adopted clearances are given in the following table of tunnel data:

Total length of single-track tunnels.......	15.57 miles
Total length of river tubes................	5.40 "
Inside diameter of tube tunnels...........	19.00 ft.
Distance from top of rail to crown of tube tunnel arch	16.00 "
Minimum top clearance over car roof to crown	1 ft. 9 in.
Distance from tunnel invert to top of rail..	2 ft. 2 in.
Height of top of tunnel benches above rail..	5 ft. 6 in.
Width between benches....................	11 ft. 8 in.
Width of bench (River sections)..........	3 ft. 8 in.

Drawings giving full particulars of the tunnel dimensions are found in other papers. The average clearance from the car roof to the crown of the tunnel arch is 21 in., and it was intended, in the event of the use of an overhead conductor, to give a minimum clearance of 6 in. from the crown to the conductor and 15 in. from the conductor to the car roof. In order to obtain maximum space for the insulators carrying the conductor, it was decided to construct pockets in the concrete

of the tunnel roof, these being 15 by 24 in., 5 in. deep, and 10 ft. from center to center.

Interior Arrangement.—The circular cross-section of the tunnel provided an excess of clearance at the horizontal diameter, which President Cassatt suggested might be utilized to contain high side-benches of concrete, to form vertical walls for the protection of trains in case

CROSS-SECTION OF RIVER TUNNEL

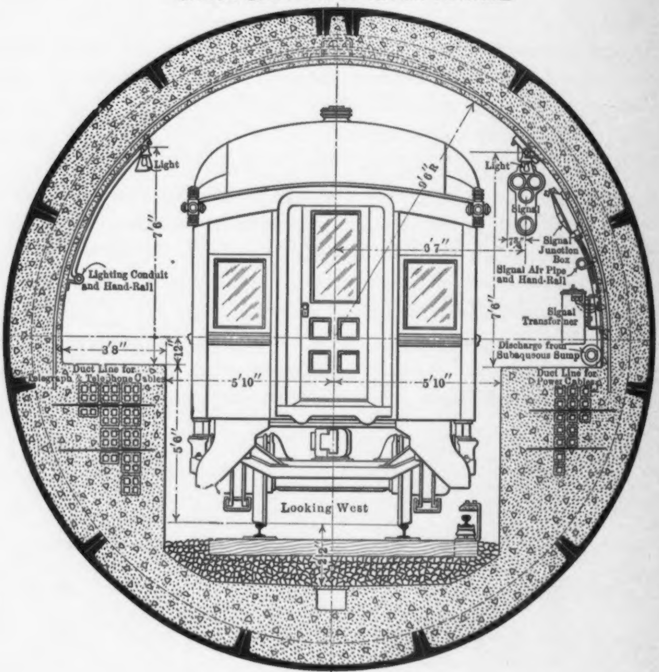


FIG. 9.

of derailment, and also for walkways for passengers in case of accident, and for employees. (See Fig. 9.) They also provide convenient and safe means for housing the electric cables. These benches were made with the top 5 ft. 6 in. above the rail, or about 18 in. above the car floor, and give normally 10 in. clearance from the sides of the car. Fig. 1, Plate XCIII, is a view of the interior of the tunnel, showing the signal equipment and other facilities.

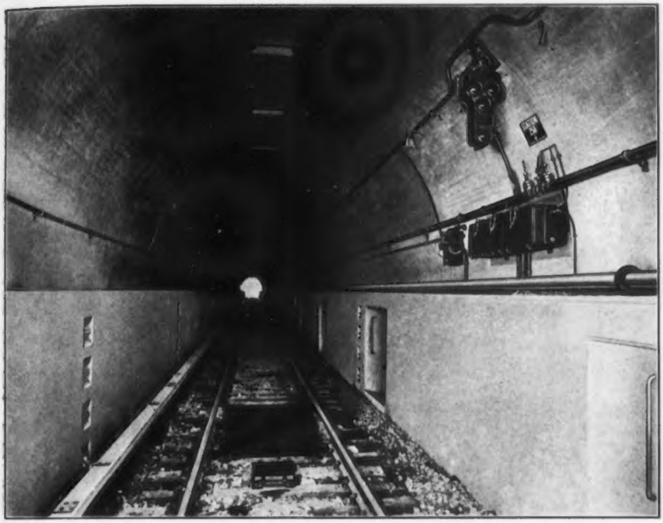


FIG. 1.—INTERIOR OF TUNNEL, SHOWING SIGNAL EQUIPMENT AND OTHER FACILITIES.

FIG. 2.—VERTICAL-SHAFT MOTORS FOR CENTRIFUGAL PUMPS IN NINTH AVENUE SUMP.

The walkways in the river tubes are 3 ft. 8 in. wide, but in certain portions of the land section their width is only 2 ft. 4 in., as required by the width of the streets traversed. In installing signals, piping, and other apparatus in the tunnels, only one bench (that on the right hand side) has been obstructed, and this only partly; the other bench has been left entirely clear. Both benches have been provided with hand-rails, and the tunnel lights are placed above them in a convenient location for inspection and renewal.

It will be noted, from other papers treating of the tunnel construction, that refuge niches and ladders for trackmen are provided in the benches at intervals of 25 ft. It will also be noted that the tunnels are provided with cross-passages between pairs in the land sections. These passages are closed by doors, so that the tubes throughout are distinct, and ventilation is positive.

Drainage.—The drainage is described under the general heading, "Drainage System."

Lighting.—The tunnels are lighted continuously by a source of power which is entirely independent of the traction system. Each tunnel, moreover, has two circuits which are independent of each other and are fed from separate transformers and switching panels. The primary source of the lighting current is the 60-cycle generators used for the general auxiliary power system, and located in the Long Island power-house and also in the 31st Street Service Plant.

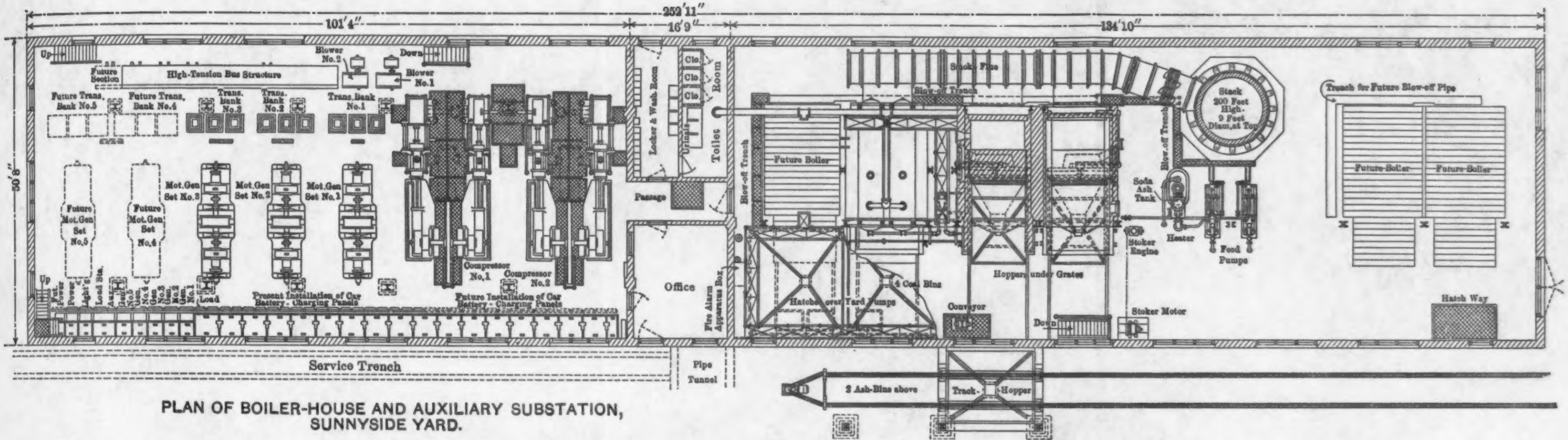
The lighting circuits are run in pipe conduits on the tunnel walls above the benches, and on one side of the tunnel serve as a hand-rail. The lamps are of the Tungsten type, of 25-watt rating, 20-c.p., and operate at 33 volts, being connected 8 in series on a 252-volt circuit. They are 50 ft. apart, on each side of the tunnel, and staggered so as to give a lamp for each 25 ft. of the tunnel length. The lamps are 7 ft. above the tunnel side-benches, and have enameled steel reflectors to throw the light in the direction of the movement of trains. Arrangements are made at various points in the lighting circuits for the attachment of portable extension connections for lamps to be used in repair work on various apparatus in the tunnels. The control of the current is from switch-boards in the auxiliary power sub-stations in the shafts.

Ventilation.—Satisfactory ventilation for the tunnels was considered to be of great importance, as it was desired that, not only should

the tunnels be safe under all emergency conditions, but that there should be at no time noticeable discomfort to passengers. Two general conditions were to be provided for: first, purity of the air in normal operation; and, second, requisite ventilation for an indefinite period in case of stoppage of trains in the tunnel from accident or other cause. It was thought, and afterward verified by trial, that the piston action of the trains when in motion would be an effective means of changing the air, as each tube contains only one track, and is isolated from the adjoining tube and open at each end to the free air. Where piston action has proved insufficient, as in the case of the deep tubes in London, it would seem to be because of the lack of sufficient free opening to the atmosphere, especially at the ends, and because of the by-passing of the air from one tube to another at stations. A special ventilating system, therefore, is needed only to provide air to a stalled train in an emergency, or to dissipate smoke and fumes from an electric arc, the possibility of which conditions was thought of sufficient importance to warrant the installation of a very complete forced-draft ventilating plant. To obtain the benefit of his experience in tunnel ventilation, the Company engaged Charles S. Churchill, M. Am. Soc. C. E., as an expert to consult with the writer in devising a proper system for the 15½ miles of tunnels comprised in the terminal railway. It was determined that the air in the cars should not be allowed to contain more than 8 parts of carbon dioxide per 10 000, requiring 30 cu. ft. of fresh air per min. to each passenger. To insure this quantity of fresh air in the cars, it was thought advisable to furnish more, namely, 50 cu. ft. per passenger per min. in the tunnels, and the fan equipment was designed to meet this requirement, having due regard to emergency conditions and the occasional irregular spacing of trains. The quantity of air required per section of tunnel on this basis is about 60 000 cu. ft. per min., which will completely change the contents of the tubes three times per hour.

Plans for producing the requisite ventilation by exhaust, by pressure, or by a combination of both were considered. The system found best adapted to the local conditions was patterned after the one devised by Mr. Churchill, and used on the Norfolk and Western Railway and elsewhere. It is a forced-draft system in which a constant and uniform current of air is induced in the tunnel by forcing, in the direction of the traffic, the required volume of air into the portal. A

PLATE XCIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1165.
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.



PLAN OF BOILER-HOUSE AND AUXILIARY SUBSTATION, SUNNYSIDE YARD.

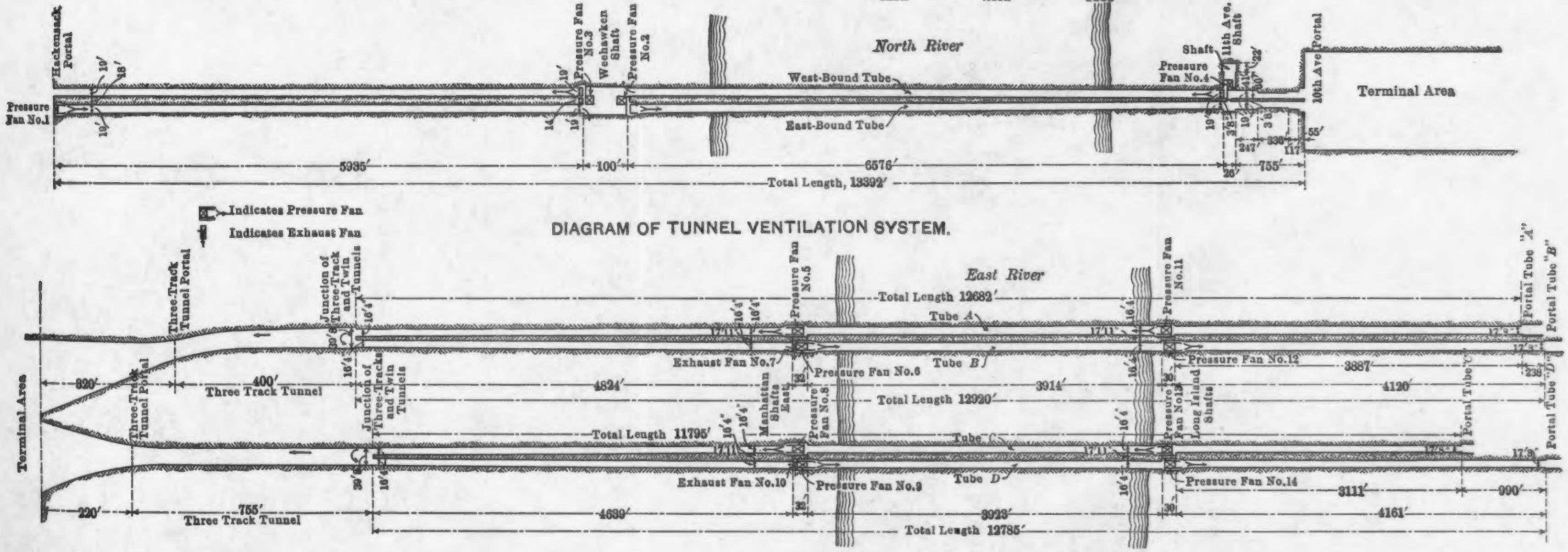


DIAGRAM OF TUNNEL VENTILATION SYSTEM.

divided nozzle, in the form of a tapering flue, is placed on each bench-wall for this purpose. This method requires no obstructing flues in the tunnels themselves, the nozzles being at the portals only, a consideration of great importance in keeping the side-benches free for walkways. The arrangement of tunnels and shaft openings required in all fourteen sets of ventilating apparatus at different points, as shown by the lower part of Plate XCIV. A list of the locations, with fan capacities obtained by test under maximum conditions, is given in Table 4.

TABLE 4.—TUNNEL VENTILATION.

Location.	Fan No.	Blower or exhauster.	Direction of air—east or west.	Diameter of wheel, in inches.	Approximate length of tunnel ventilated, in feet.	Fan capacity at normal speed, in cubic feet per minute.	Velocity at fan outlet, in feet per minute.	Brake-horse-power at motor.
North River — Hackensack Portal. Building over portal.....	1	B	E	60	5 900	87 000	3 920	48.6
North River, Weehawken Shaft. In room between tracks below bench level...............	2	B	E	60	6 600	125 800	5 670	97.0
	3	B	W	54	6 000	100 800	5 580	56.8
North River—Eleventh Avenue Shaft. In room at track level on north side of west-bound tube..........................	4	B	W	60	6 600	107 000	4 830	68.5
East River — First Avenue Shafts. In building located at ground level over tracks 3 and 4..........................	5	B	W	72	4 800	100 000	3 130	62.0
	6	B	E	54	3 900	60 000	3 330	21.0
	7	E	E	66	4 800	59 200	4 400	27.9
East River — First Avenue Shafts. In building located at ground level over tracks 1 and 2..........................	8	B	W	72	4 800	100 000	3 130	62.0
	9	B	E	54	3 900	60 000	3 330	21.0
	10	E	E	66	4 800	59 200	4 400	27.9
East River—Long Island City Shafts. In building located at ground level over tracks 3 and 4..........................	11	B	W	54	3 900	65 000	3 600	24.3
	12	B	E	54	4 100	65 000	3 600	24.3
East River—Long Island City Shafts. In building located at ground level over tracks 1 and 2..........................	13	B	W	54	3 900	65 000	3 600	24.3
	14	B	E	54	4 200	65 000	3 600	24.3

It will be noted from Table 4 that, in two cases, exhausting instead of pressure blowers are used; these are for the purpose of causing a return current of air at the west ends of the cross-town tunnels; where they merge into three-track tunnels approaching the passenger station, the object being to prevent blowing air from the tunnels under and into the Station Building.

The blowers are of the multi-vane, "Sirocco" type, belt-driven from induction-type electric motors; and the speed of the fan can be ad-

justed, by cone pulleys, from normal, as given in Table 4, to 70% or 40% of normal, as required.

The air ducts from the fans (see Fig. 10) vary in form and arrangement to suit local conditions, but are generally rectangular in section. They were designed carefully, with bends of large radius to minimize friction, and proportioned so as to eliminate all sudden changes in velocity between the fan and the nozzle.

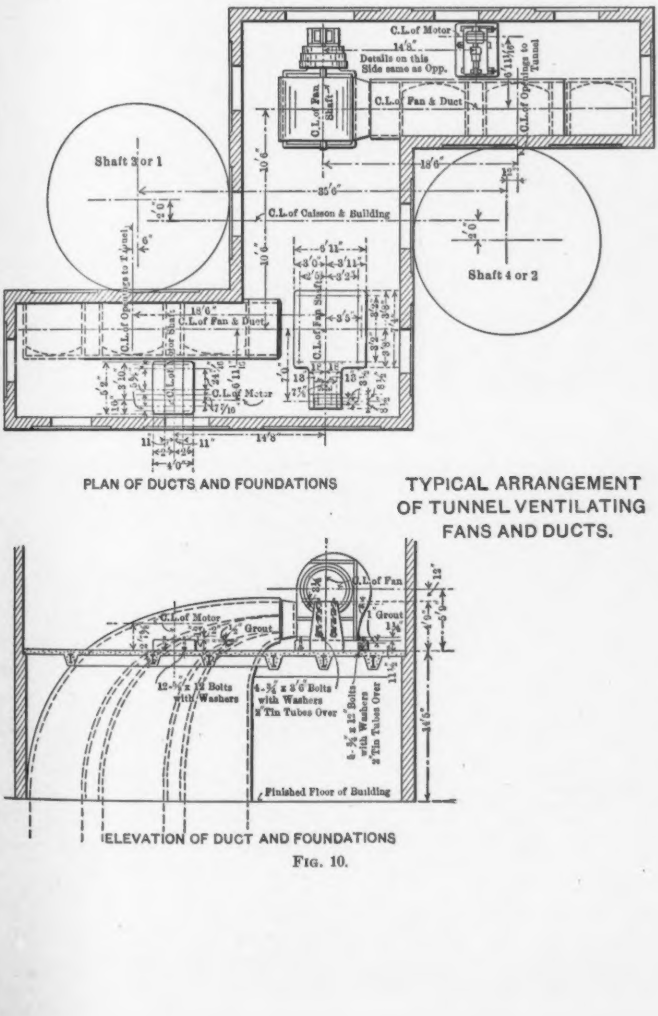
From tests made in the tunnels, with and without the fans running, it is apparent that, under normal conditions, the piston action of the trains can be relied on to give satisfactory ventilation. Records show that in the East River Tunnels the air is changed every 40 min. by the passage of trains during non-rush hours, and every 15 min. during rush hours.

The average velocity of the air in the East River Tunnels due to the action of the fans alone is about 8 miles per hour. This is increased by the passage of trains to more than 30 miles per hour, the latter figure, of course, depending on the number of cars in the train, and the speed.

It is evident, therefore, that in regular operation, the fans need not be run, and provision has been made to start and stop them, as required, from two central points, the power-house for the East River Tunnels, and the Service Plant for the North River Tunnels.

Tunnel-Alarm System.—The tunnels are equipped with a special safety device which has two functions, one to cut off the current in a given section of the third-rail, and the other to send a fire-alarm call. The system consists of a series of alarm boxes, set about 800 ft. apart. Each box is numbered, and contains two levers, colored blue and red, respectively. The blue lever is marked "POWER," and when pulled trips the circuit-breakers controlling the third-rail section adjacent to the box, thus cutting off the power and at the same time sending a call of two rounds of the alarm box number to the connected indicators. The red lever is marked "FIRE," and when pulled performs the same function as the power lever, but sends in two additional rounds of the box number.

The box mechanism is operated by clockwork, set in motion by the winding of a spring when the lever is pulled; the clockwork actuates electric contacts in the circuits, controls an auxiliary tripper to the section circuit-breaker, and spells the box number on the station



TYPICAL ARRANGEMENT OF TUNNEL VENTILATING FANS AND DUCTS.

FIG. 10.

indicators. Each box is provided with an interference magnet which prevents sending in an alarm from another box if one box on the circuit is in operation. Current for actuating the alarm circuits is obtained from storage batteries in the various sub-stations.

TABLE 5.—Tunnel Alarm System.

General-alarm circuits.	Location.	Total No. of boxes in each tunnel.	Local alarm circuits. No.	No. of boxes in each local circuit.	Location of switch-board for local circuits.
No. 1, North River.....	South Tunnel..	19	1	9	Sub-station No. 3.
			2	10	" " 2.
	North Tunnel..	19	3	9	Sub-station No. 3.
			4	10	" " 2.
No. 2, East River.....	Tunnel No. 1...	20	5	4	Sub-station No. 2.
			6	9	Long Island City Power-Station.
			7	7	" " "
	Tunnel No. 2...	18	8	4	Sub-station No. 2.
			9	9	Long Island City Power-House.
			10	5	" " "
No. 3, East River.....	Tunnel No. 3...	20	11	4	Sub-station No. 2.
			12	9	Long Island City Power-Station.
			13	7	" " "
	Tunnel No. 4...	20	14	4	Sub-station No. 2.
			15	9	Long Island City Power-Station.
			16	7	" " "

The indicators, recording the character of the alarm and the location of the box sending it, are in the offices of the Train Director, the Train Despatcher, and the Power Director, and in the power sub-station controlling the traction current for the section in question; the indication is also repeated to the interlocking-switch cabin controlling train movements to the section. In case of a partial short circuit on a car or at the third-rail, which may maintain an arc, or in case it is desired to work around defective apparatus under a standing train, the current may be cut off from the third-rail of the section by pulling the "Power" lever. In case of a serious fire or other emergency, the "Fire" lever may be pulled, and then the Railroad Fire Department at the Station and the emergency crews will respond. In either case the person pulling the lever is instructed to get into direct communication with the Train Director by telephone from a near-by telephone box, and to explain the trouble so that an order governing subsequent procedure in responding to the alarm or resetting the circuit-breakers may be given.

There are sixteen local or "Power" alarm circuits, corresponding to the section-controlling breakers, and there are three general or "Fire"

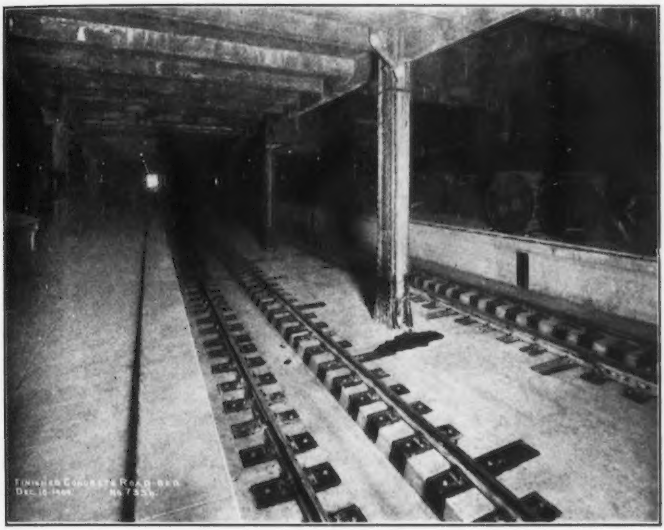


FIG. 1.—FINISHED CONCRETE TRACK.

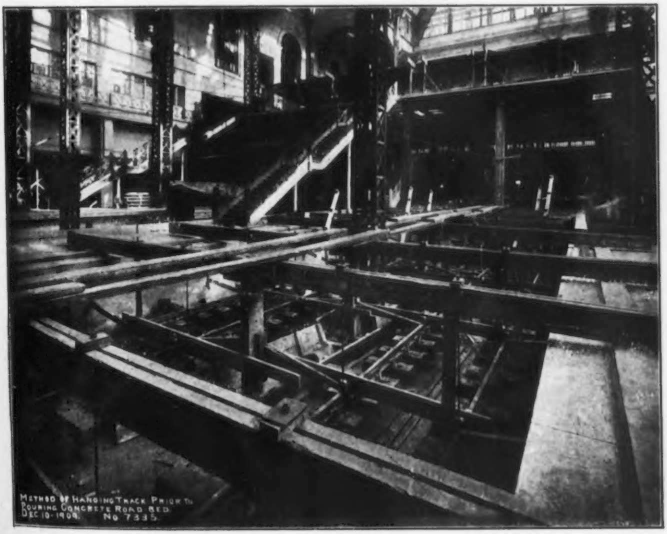


FIG. 2.—METHOD OF SUPPORTING TRACK STRUCTURE TO RECEIVE CONCRETE BASE.

alarm circuits, connected to switch-boards in the power-house at Long Island City, the Service Plant in 31st Street, and the traction substation at the Hackensack Portals of the tunnels.

TRACK.

The portion of the Terminal railway track construction assigned to this Department consisted of that in the tunnels, and in the Station and Sunnyside yards. The standards adopted are in general those of the Pennsylvania Railroad, with certain modifications in detail dictated by the Maintenance of Way Department for the better adaptation of the track to the peculiar local conditions.

Tunnel Track.—It was desired to adapt the track to high-speed running, with a minimum of vibration of the track or tunnel structure, and to reduce noise as far as practicable; also to permit of ease of renewal, without disturbance of the tunnel concrete lining. For these reasons, it was decided to adopt ballasted track, rather than any special form built into the tunnel structure, although, as mentioned later, a short section of track having a concreted base was put in the land section of two of the tubes, for experimental purposes.

The rail is 100 lb. per yd., and is of the new "Pennsylvania" section, and of open-hearth steel, to the Road's specifications. The joint angle-bars are of the six-hole type, with an extended flange below the rail base, and have 1-in. bolts. The base has also a special cross-section providing space for copper bonds between rail and splice.

The ties are of black gum and yellow pine, creosoted, the minimum dimensions being 8 in. face, 7 in. thick, and 18 ties to the rail length of 33 ft. All track is tie-plated with special rolled-steel plates, 7 by 13 in. and $\frac{5}{8}$ in. thick. These plates have shoulders inside and out, and are secured to the ties by four $\frac{3}{4}$-in. lag-screws. Under each plate is placed a pad of compressed hair-felt, $\frac{1}{2}$ in. thick, the tie being dapped out to receive the pad. The rail is secured to the tie through the plate by two 1-in. lag-screws, each bearing on the rail flange and shoulder of the plate.

The ballast is of trap rock, screened through $1\frac{1}{2}$-in. mesh, and laid for a depth of 12 in. under the ties. This ballast was crushed on the Company's property, using the rock taken from the Bergen Hill Tunnels.

Station Yard Track.—Two types of track construction were adopted for the yard (see lower part of Plate LXXVIII); one, the standard ballasted, and the other a special form of concrete bedding for the short tie-blocks which carry the rails. Ballasted track is used through the switches and in the storage yard, and the concreted-base track adjacent to the platforms. The ballasted track is of the same standards as used in the tunnels, except that the ballast is of ¾-in. rock, and the ties are not creosoted.

Concrete-Base Track.—For the track under the Station Building and adjacent to the passenger platforms, it was desired to provide a form of construction which would present a smooth surface, and could readily be kept clean. This was especially desirable where cars stand and drip oil and water on the track structure, and at places where rubbish may be thrown on the tracks by passengers. To devise the proper form of track for this purpose, a special committee was formed of Operating Officials of the Pennsylvania Railroad. This committee recommended a special form of track laid on wooden blocks embedded in a concrete base. This form of construction is shown in the lower part of Plate LXXVIII, and in Fig. 1, Plate XCV. A single track length of 14 600 ft. of this type was laid adjacent to the platforms, except at switches and cross-overs, where standard ballasted track was used. In general, the concrete surface was laid on the rock of the sub-grade, but in places where the sub-grade consisted of loose rock back-filling, crossed by drains and subways, it was necessary to secure uniformity for the concrete base by specially ramming the filling and using rod reinforcement or bridging in the concrete. The concrete used is a 1:2:4 mixture of Portland cement, sand, and washed Cow Bay gravel.

The track was first laid complete with its fastenings to the tie-blocks, and then raised and leveled with great care to the proper grade and alignment by hanging the structure from a timber bridging carried on the station platforms, as shown by Fig. 2, Plate XCV; the concrete mixture was then poured, tamped, and allowed to set; then the bridging was removed. The cost of this track complete, under the special conditions obtaining in this place, was $6.27 per lin. ft. for the base, and $2.67 per lin. ft. for the tie-blocks and fastenings, making a total cost of $8.94 per lin. ft.

In the Station area, of course, this track is subjected to slow-speed running only. In order to test its application to high-speed running,

PLATE XCVI.
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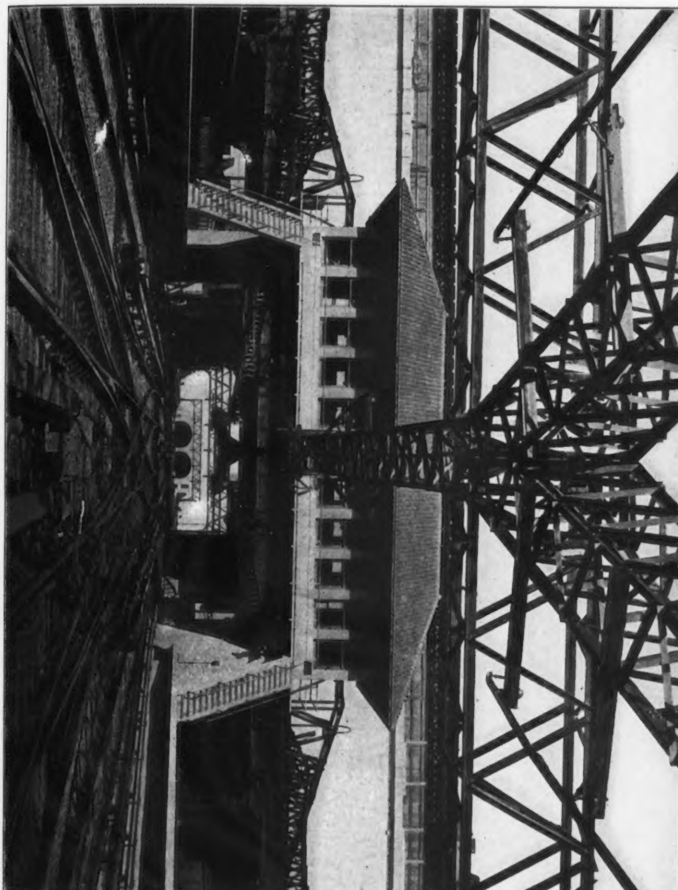


SIGNAL CABIN "A," LOOKING TOWARD TUNNEL PORTAL AT TENTH AVENUE.

two short sections, each of 720 ft., were laid in two of the East River Tunnels (No. 1 and No. 2), immediately east of the Long Island shafts. In this case the concrete base for the track was laid directly on the concrete invert of the tunnel lining, and the general methods of construction were the same as described for similar track in the Station Yard.

Sunnyside Yard Track.—The main running tracks are laid with 100-lb. rails, on oak ties; the yard tracks are of 85-lb. rails, on untreated yellow pine ties. All rail is placed on tie-plates, without the hair-felt pad beneath, and the rail and plates are secured to the ties by standard ⅝-in. spikes.

Third-Rail Ties.—Each fifth tie in the track is used at one end as a seat for the third-rail insulator and for the bracket to support its covering; therefore, they are longer than the standard ties, or 9 ft. 3 in.

Frogs and Switches.—All frogs and switches are according to the Pennsylvania Railroad standards; generally, No. 8 frogs are used and 18-ft. point switches, housed in the stock rail; in a few cases clearance has required the use of a No. 7 turn-out. In the Station Yard all frogs and crossings have hardened manganese steel points. The general quantities relating to track are as follows:

Total length of track laid, including Meadows Division and Manhattan Transfer yard	94.52 miles.
Ballast used	268 870 cu. yd.
Number of switches	357
Number of slips	46
Number of crossings	14

Buildings for Railroad Facilities.

Sixty-four separate buildings were required for the Terminal Railroad. They are listed in Table 6 as to location and purpose. The details of design and construction of these various buildings differ greatly, and cannot be described with any fullness in this paper; certain features, however, may be referred to.

Station Yard Buildings.—The Station Yard buildings are small, and are at convenient points in the yard to provide offices, store-rooms, locker- and toilet-rooms, for the use of employees on duty at the track level. All are of fire-proof construction, and of uniform architectural design; with the exception of Nos. 2 and 5 (which are of hollow tile covered

TABLE 6.—(*Continued.*)

Description.	Location.	Type of construction.	Size, in feet.
STATION YARD—(*Continued*).			
U. S. Post Office	Eighth Avenue, 31st to 33d Streets	Granite,	335 by 375
Yardmaster's Office. One story	Eighth Avenue and 33d Street	Reinforced concrete	13 by 38
Trackmen's Building. One story	Eighth Avenue and 33d Street	Tile and stucco	9 by 19
Signal Cabin "B." One story and basement	Eighth Avenue and 33d Street	Reinforced concrete	10 by 36
Track, Signal, and Third-rail Tool-house. One story.	33d Street between Seventh and Eighth Avenues	Expanded metal and stucco	21 by 86
Service Power-plant. Contains Sub-station No. 2	31st Street between Seventh and Eighth Avenues	Granite	97 by 161
Pennsylvania Station	Seventh to Eighth Avenues, 31st to 33d Streets	Granite	430 by 784
34th Street. Exit Stairway, Head-house	33d Street between Seventh and Eighth Avenues	Brick	30 by 92
Assistant Station Master's Office. One story	Seventh Avenue and 33d Street	Tile and stucco	9 by 12
Assistant Yard Master's Office. One story	Seventh Avenue and 32d Street	Reinforced concrete	10 by 36
Signal Cabin "C." One story and basement	Seventh Avenue and 33d Street	Reinforced concrete	12 by 35
Signal Cabin "D." One story and basement	Seventh Avenue and 32d Street	Reinforced concrete	11 by 35
EAST RIVER SECTION.			
Shaft-house, Tunnels 4 and 3. Auxiliary Sub-Station "D"	First Avenue, Manhattan	Brick	40 by 45
Shaft-house, Tunnels 2 and 1. Auxiliary Sub-Station "C"	First Avenue, Manhattan	Brick	40 by 45
Shaft-House, Tunnels 4 and 3	Front Street, Long Island City	Brick	40 by 64
Shaft-house, Tunnels 2 and 1. Auxiliary Sub-station "B"	Front Street, Long Island City	Brick	40 by 64
Traction Power-house. Sub-Station No. 1	Front Street, Long Island City	Brick	200 by 265
Trackmen's Tool-house	West of Portals 3 and 4, Long Island City	Frame	16 by 20
SUNNYSIDE YARD.			
Telephone Terminal House	Over Portals 1 and 3	Frame-stucco	8 by 9
Signal Cabin "F." Two stories and basement	West of Thomson Avenue	Brick	17 by 27
Trackmen's Tool-house. One story	West of Thomson Avenue	Frame	16 by 20
Signal Cabin "Q," Yardmaster's Office. Two stories.	East of Queensboro Bridge Approach	Brick	14 by 83
Sand-house. One story	160 ft. east of Queensboro Bridge Approach	Brick	25 by 32

TABLE 6.—TERMINAL RAILROAD BUILDINGS; LISTED CONSECUTIVELY FROM THE WEST.

Description.	Location.	Type of construction.	Size, in feet.
MANHATTAN TRANSFER YARD.			
Signal Cabin "N" (Switch Station No. 4-B, in basement)	West of Transfer Station	Brick	17 by 27
Signal Cabin "S"	East of Transfer Station	Brick	17 by 27
Trackmen's Tool-house	East of Transfer Station	Frame	16 by 20
Transfer Station and Yard Buildings	In Transfer Yard	Described in paper by E. B. Temple, M. Am. Soc. C. E., *Transactions*, Vol. LXVIII, p. 75.	
MEADOWS SECTION.			
Trackmen's Tool-house	On Bridge over N. Y. Div	Frame	16 by 20
Sub-Station No. 4	East of Bridge over N. Y. Div	Brick	52 by 105
Switch Station No. 4-A	Hackensack River Bridge	Galvanized iron	9 by 13
Signal Cabin "W"	Hackensack River Bridge	Galvanized iron	9 by 13
Switch Station No. 3-B	West of Erie Railroad Yard	Brick	9 by 11
Trackmen's and Third-rail Tool-house. Triple House.	Hackensack Portals	Frame	20 by 47
Sub-Station No. 3	Hackensack Portals	Brick	52 by 105
NORTH RIVER SECTION.			
Blower-House	Over Hackensack Portals	Granite	24 by 51
Employees' Dwellings. Two double two-story houses.	Above Hackensack Portals	Brick	31 by 46
Trackmen's Tool-house	Weehawken Shaft	Expanded metal and stucco	7 by 16
Shaft Head-house	Eleventh Avenue Shaft	Corrugated iron	27 by 39
STATION YARD.			
Track and Signal Building	Tenth Avenue Portals	Reinforced concrete	12 by 25
Car Battery-Charging House. Two stories	31st Street and Ninth Avenue	Reinforced concrete	12 by 19
Car Inspectors' and Cleaners' Building. Two stories.	Ninth Avenue and 33d Street	Reinforced concrete	10 by 49
Signal Cabin "A"	Between Ninth Avenue and Post Office	Steel-concrete	21 by 62

TABLE 6.—(*Concluded.*)

Description.	Location.	Type of construction.	Size, in feet.
SUNNYSIDE YARD—(*Continued*).			
Carpet shed	50 ft. east of Sand-house	Steel shed	34 by 89
Commissary Building. P. R. R.—67 by 97 ft. Pullman—67 by 161 ft. Two stories	100 ft. east of Carpet shed	Brick	67 by 258
Hose-house	South Yard, west of Honeywell Street	Frame	6 by 6
Store-house. Two stories	56 ft. east of Commissary building	Brick	67 by 162
Car-Battery house. One story	30 ft. east of Store-house	Brick	67 by 103
Pipe-rack	30 ft. east of Car-Battery house	Corrugated iron	21 by 21
Aux. Sub-Station "A" and Boiler-house. One story	181 ft. east of Pipe-rack	Brick	51 by 253
Hard coal and charcoal bin	25 ft. east of Boiler-house and 35 ft. west of Honeywell Street	Frame	11 by 81
Switching Station No. 1-A. One story	South of South Yard, West of Honeywell Street	Brick	18 by 35
Tool-house	65 ft. east of Honeywell Street	Frame	16 by 20
Oil-house	250 ft. east of Honeywell Street	Brick	51 by 67
Engine-house	60 ft. east of Oil-house	Concrete	72 by 161
Scrap-bin	79 ft. east of Engine-house	Frame	12 by 36
Iron-rack	29 ft. east of Scrap-bin	Corrugated iron	21 by 21
Signal Cabin "H." Two stories and basement	600 ft. west of Harold Avenue	Brick	17 by 27
Wheel-shop. One story	50 ft. east of Iron-rack	Expanded metal stucco	41 by 81
Auxiliary Store-house	Between Wheel-shop and Wheel-shed	Expanded metal stucco	10 by 30
Wheel-shed	60 ft. east of Wheel-shop	Steel shed	50 by 100
Signal Cabin "R." Two stories and basement	200 ft. west of Harold Avenue	Brick	17 by 27
Employees' Dwellings. Two double, two-story houses	Laurel Hill Avenue	Brick	31 by 46

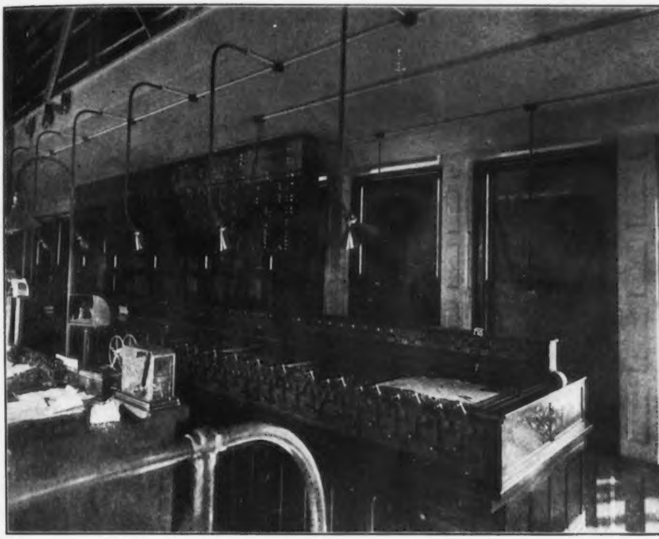


FIG. 1.—INTERIOR OF INTERLOCKING CABIN "A."

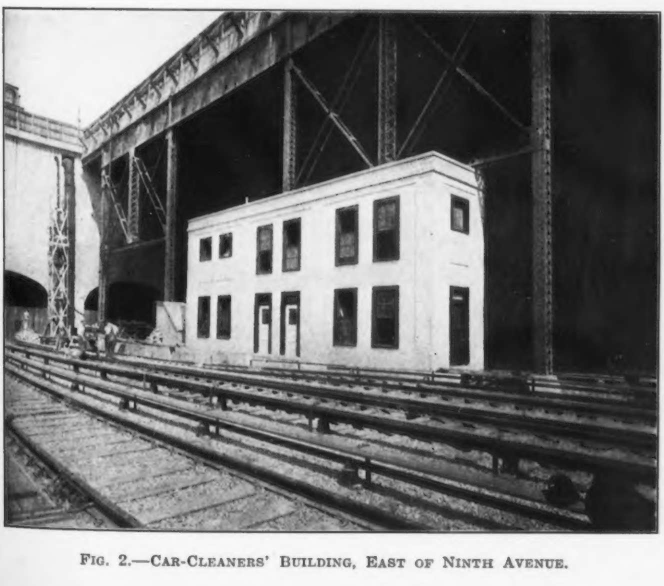


FIG. 2.—CAR-CLEANERS' BUILDING, EAST OF NINTH AVENUE.

with cement plaster), they are of reinforced concrete without exterior ornamentation. The doors and windows are set in depressed panels, and a parapet accented by raised band courses finishes the roof. It will be noted from Table 6 that nearly all buildings have toilet facilities, which, in fact, was an essential feature in determining their location, as sewer connections had to be made through ejectors located at fixed points in the subway system under the tracks.

Signal Cabins.—There are four signal cabins in the Station Yard, and all are of special design to meet special physical and operating conditions. Three of the cabins are under the buildings and street viaducts. They are of restricted dimensions because of the close clearances, and of irregular shapes in order to obtain the maximum room inside and the least obstruction to the operator's view of the tracks. Cabin "A," Plate XCVI, is the main interlocking station of the Terminal, controlling all the movements to and from the west and the main-ladder switching movements. In order to obtain a central location and unrestricted view, the building was placed on a bridge over the throat of the ladder tracks about midway between the Post Office Building and Ninth Avenue. This gives the cabin a prominent position in the open yard, and it was thought to justify the design of a somewhat pretentious structure. The building is of the monolithic concrete type, and perhaps might be termed a reinforced concrete building, although, because of its spanning the tracks, and the fact that it serves as a support for the overhead third-rail and signal structures, a considerable quantity of structural steel is buried in its walls; thus it is not a purely reinforced concrete structure. The architecture is of the Mission type, with wide overhanging eaves and low ridged roof, covered with red Spanish tile. Owing to its location over and adjoining the switchwork of the tracks, special care was taken to protect the supporting walls in case of train derailment. At the east the station platforms perform this function, and on the west were placed very massive wedge-shaped fenders composed of 80-lb. T-rails embedded in concrete and carried below and under the track system. The entire floor space of the cabin is occupied by the operating-room, containing the interlocking machine on the floor and the relays and wiring in a gallery above; the gallery girders also act as anchor arms for the cantilever structures attached to the cabin and used for supporting the overhead rail and signals.

All signal wiring is carried in a false floor above the concrete floor of the cabin and in ducts through the side-walls and into a basement extending under the entire cabin below the tracks, where switch-boards, storage batteries, and other apparatus are located. From this basement the wire conduits are carried in a special subway (referred to elsewhere) which communicates with the subways under the yard. Fig. 1, Plate XCVII, is a view of the interior of this cabin.

The remaining three cabins, "B," "C," and "D," are under other structures; they are of two stories, a main operating floor and a basement or track-level story. The buildings are of the usual reinforced concrete construction. Fig. 2, Plate XCVII, is a view of the car cleaners' building east of Ninth Avenue.

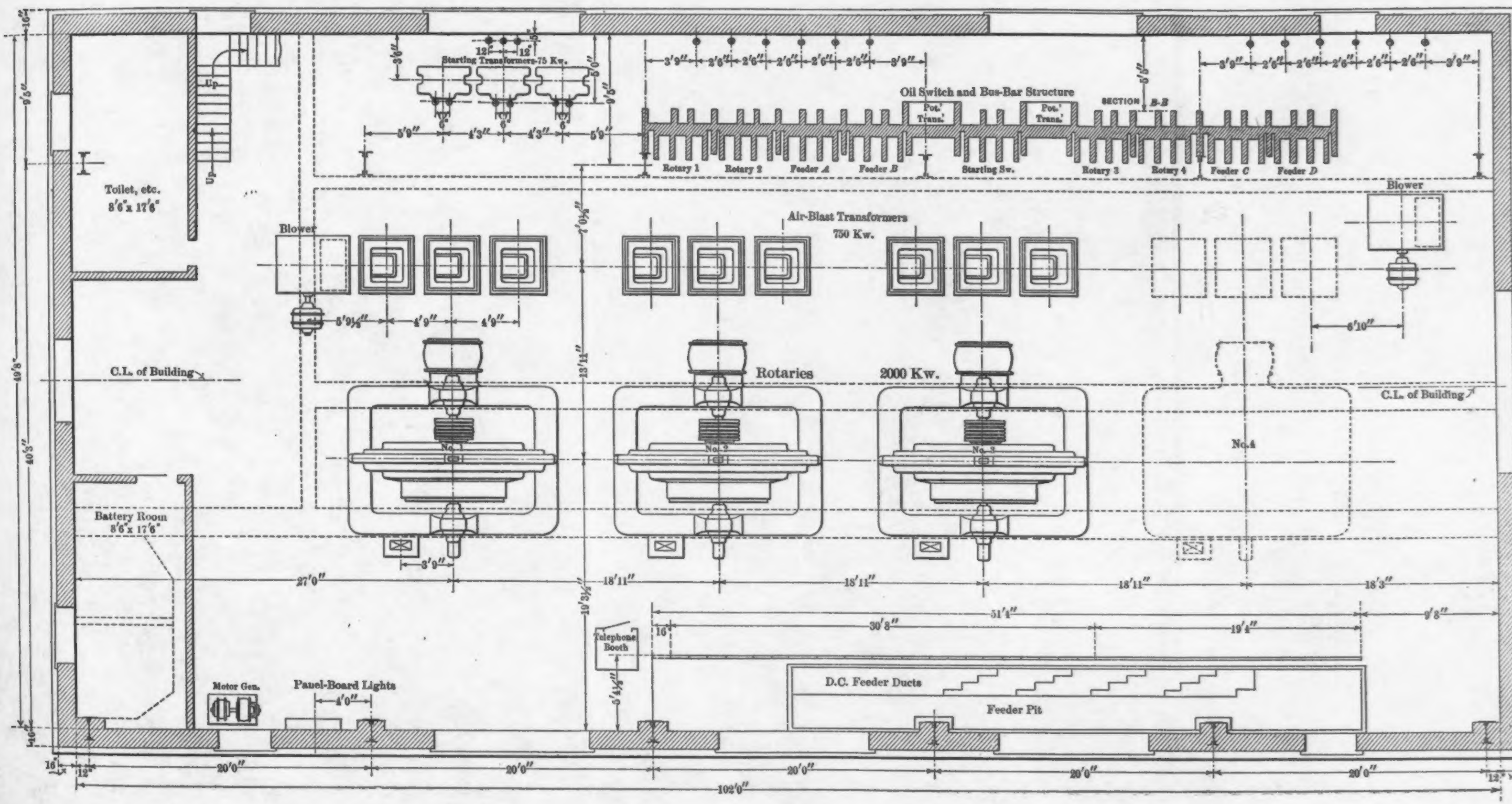
Manhattan Transfer.—Only signal cabins "N" and "S" were constructed by the writer's Department; the transfer station was designed and built by Mr. Shand as part of the general yard facilities. The signal cabins are of the usual standard design of the Pennsylvania Railroad Company.

Meadows Section.—Aside from the power sub-station buildings, these comprise small structures for electric power switching, tool-houses, and an interlocking cabin at the Hackensack draw-bridge. These latter have steel frames carried by brackets on the bridge approach, and are covered with paneled galvanized iron and lined with asbestos board.

Sunnyside Yard.—The buildings in the Sunnyside yard (Plate XCIX) are numerous and important, as is seen from Table 6, and are quite plain and of fire-proof construction. They adjoin the service yard, and are devoted to the various motive-power requirements. The outside and party walls are of hard-burned red brick, except in the cases of the engine-house and the wheeling shed, which are of steel frame covered with expanded metal and concrete plaster. The floors are generally of concrete and the roofs of steel covered with book-tile, roofing-felt, and gravel. The buildings are provided with steam heating, hot and cold water, toilet facilities, fire protection, electric lights and telephones. The interiors, with few exceptions, are fitted with metal shelving, bins, and lockers.

The engine-house and machine-shop are especially designed for ample light. The engine-house has two inspection pits, with a cross-

PLAN AND CROSS-SECTION OF HARRISON SUB-STATION



PLAN AND CROSS-SECTION OF HARRISON SUB-STATION

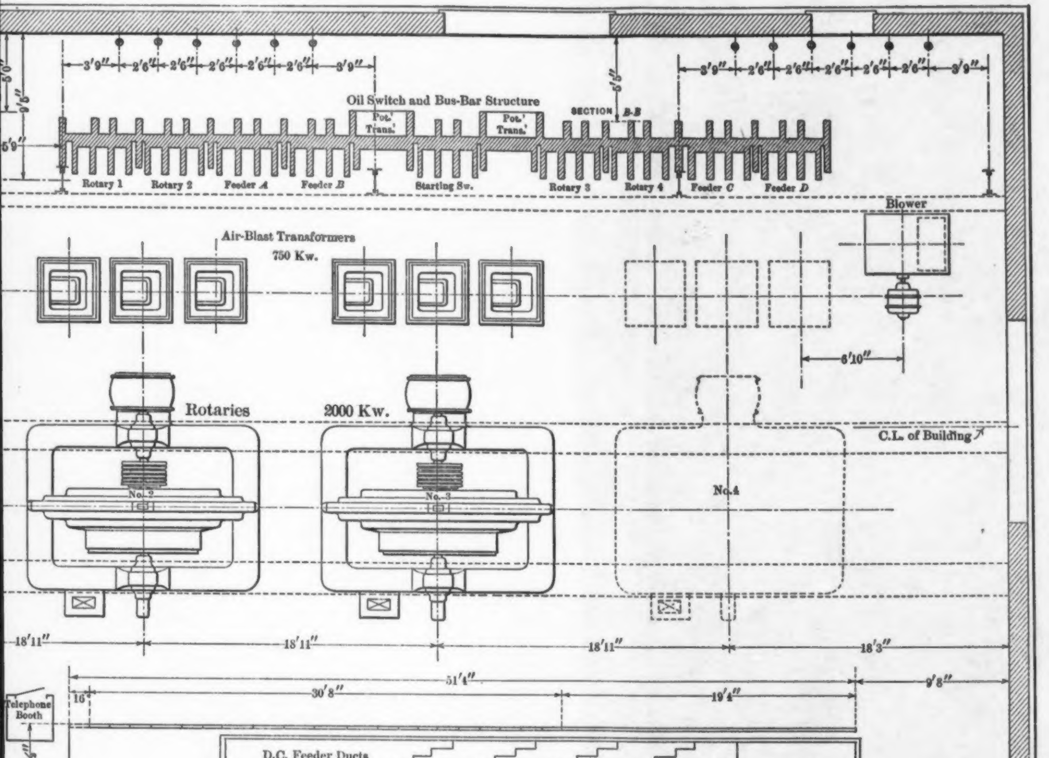


PLATE XCVIII.
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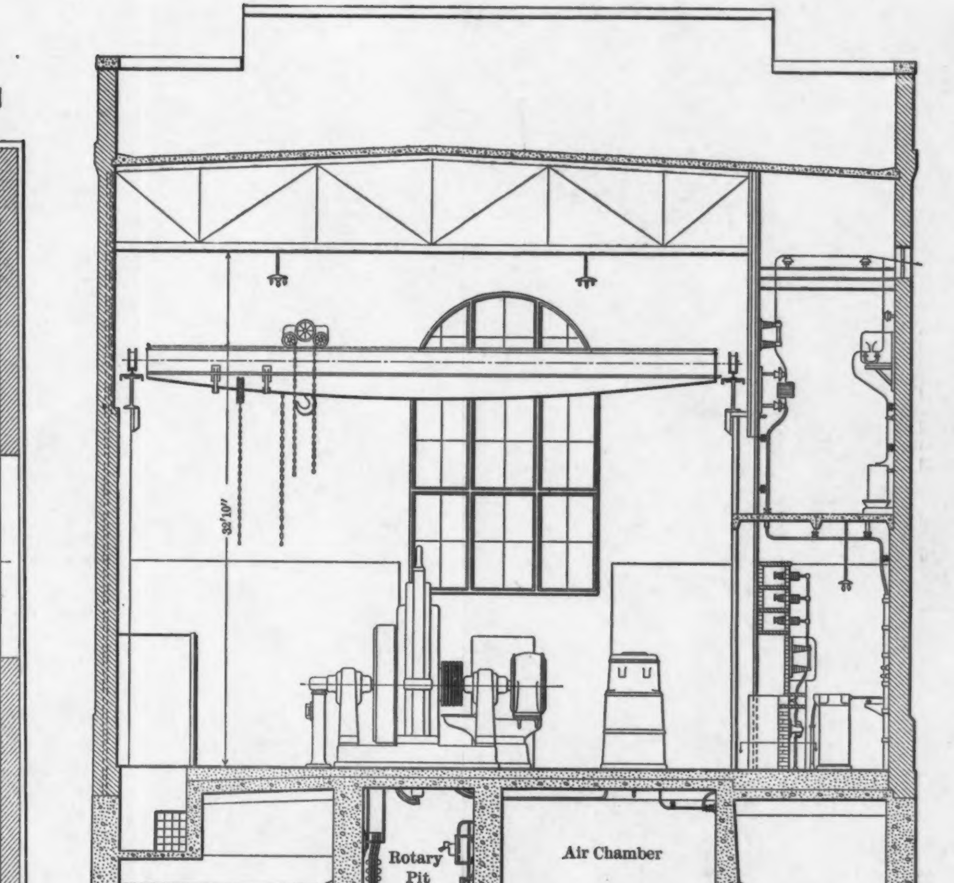
VOL. LXIX, No. 1165.
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.



pit fitted with compressed-air jacks for removing wheels. The machine-shop contains motor-driven machine tools for light repairs.

The four signal cabins are of brick, and of standard Pennsylvania Railroad Company type, except Cabin "Q," which is special and has an extension containing tool-rooms, yardmaster's offices, etc.

Power Sub-stations.—Sub-stations Nos. 1 and 2 are in the Long Island City Power-House and in the 31st Street Service Plant, respectively; Nos. 3 and 4 are on the Meadows Division, No. 3 adjoining the Hackensack Portal, and No. 4 at the east end of the Manhattan Transfer Yard. These latter buildings are similar in design and construction, and entirely fire-proof. Their exteriors are of dark red mottled brick, laid with irregular bond, and surmounted by parapet walls; the roofs are of concrete, and flat; the interior in each case (see Plate XCVIII) consists of a main operating-room with small partitioned rooms for control storage batteries, toilets, and lockers. The main room contains a gallery on one side for lightning arresters and remote-control circuit-breaker apparatus.

Blower-Houses.—Special buildings were required at certain locations for housing the tunnel-ventilation apparatus. At the Hackensack Portal a granite building was constructed for the purpose by the Chief Engineer of the North River Division. At the First Avenue Tunnel shafts two buildings were provided; one is founded on the shaft caissons, which are concrete-lined steel shells, and project slightly above the ground surface, and the other adjoins the second pair of caissons. These buildings are two stories high, approximately square, of dark red brick with irregular bond, and with concrete floors and roofs; they are thoroughly fire-proof. The interiors contain fans belted to induction-type electric motors; the ducts from the fans to the shafts are large concrete funnels with "ferro-inclave" reinforcement, carefully designed for leading the air to the shafts with minimum friction. The buildings also contain switching apparatus for the fan motors, for operating the sump pumps, and for controlling the tunnel lighting. At the Long Island City shafts, two buildings are provided for the same general purposes. These are shaped like the letter Z (see Fig. 10), and are placed over the caissons and between the shaft openings.

From each pair of tunnels three stairways rise to the surface and

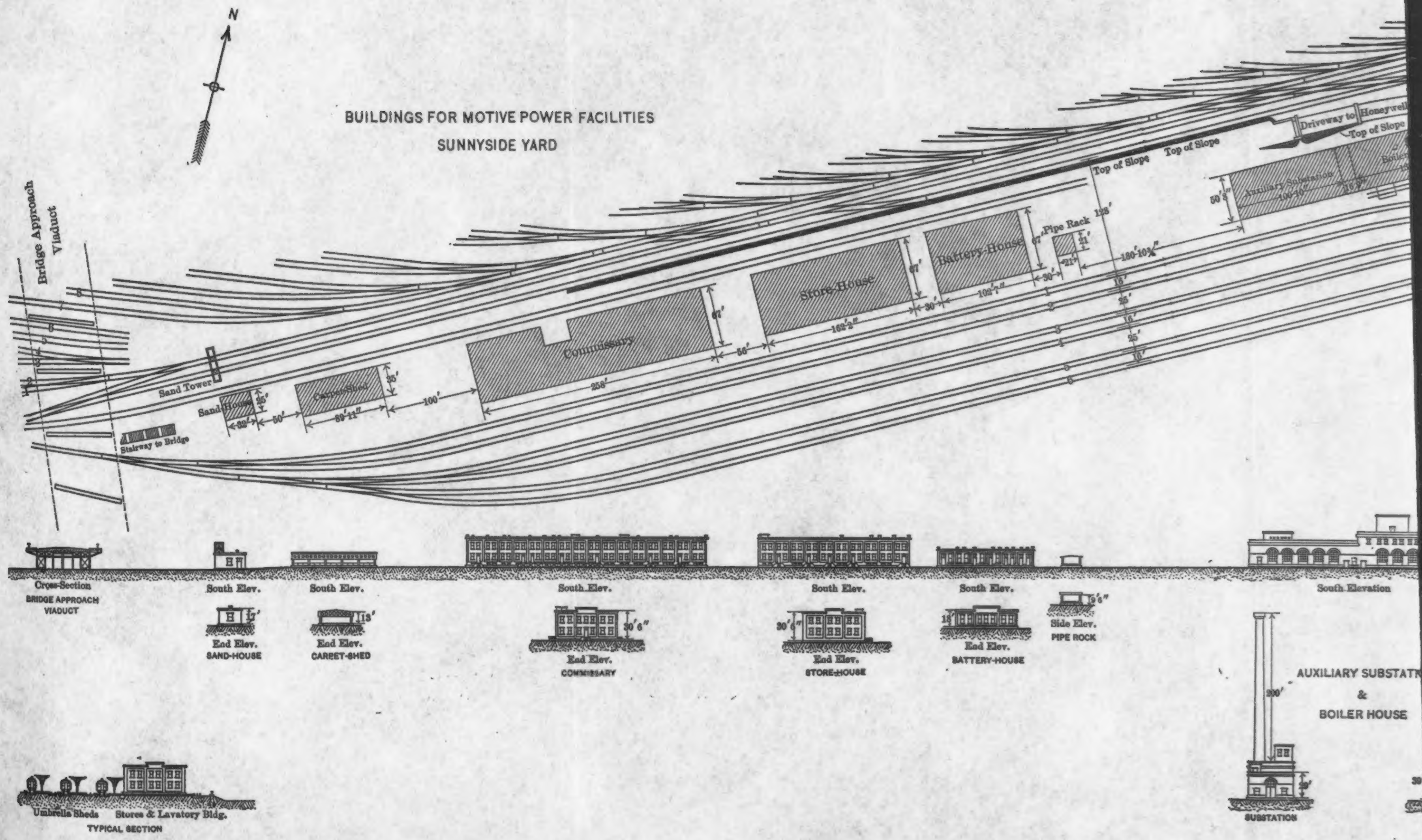
terminate in small reinforced concrete kiosks; the shaft openings, for lowering machinery, etc., are enclosed by circular concrete fences, having steel doors. Around each blower-house shaft opening a reinforced concrete wall 8 ft. 6 in. high has been built, enclosing permanently a plot of ground which it has been necessary to reserve.

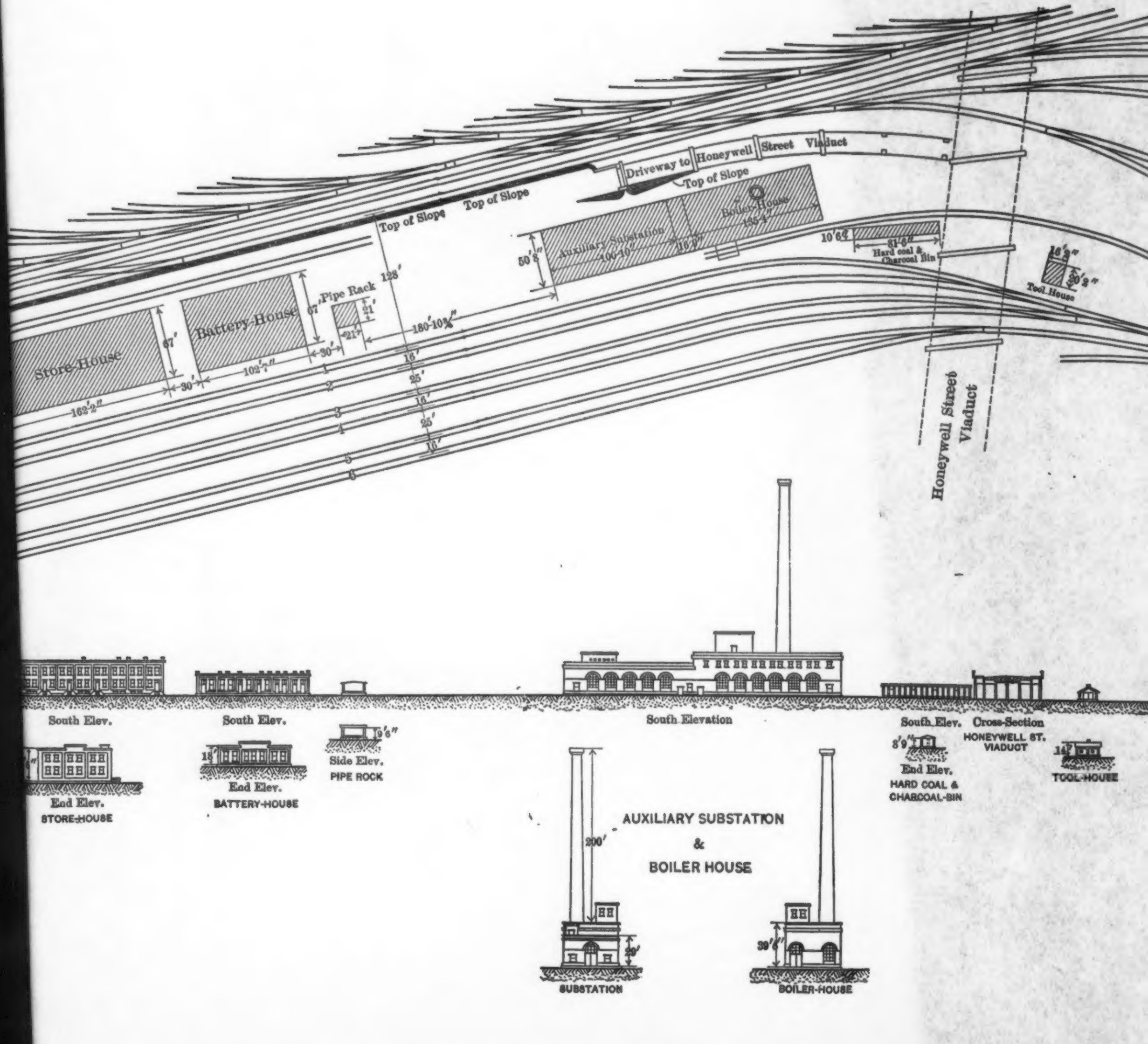
Sunnyside Yard.

This extensive yard is at the east end of the Terminal Railroad, in Long Island City. Its purpose is to furnish facilities for the storage and care of passenger train equipment using the New York Station. Practically all long-distance trains arriving at the Pennsylvania Station, when unloaded, are taken to Sunnyside Yard for turning, cleaning, and making up for the return trip. At present the Long Island Railroad does not make use of the Sunnyside Yard facilities, the turning of trains being done in the main station yard. The track plan, Plate CXVI, was devised by Mr. L. H. Barker, Resident Engineer. While the yard is a stub-end one, as regards its location at the end of the Division, yet it is double-end as regards train movements; this is accomplished by providing two loop tracks from the tunnels around the yard to its further end. Trains arriving from the New York Terminal, therefore, may enter the yard in the reverse direction and be ready to return to the Station in the same head-end order, as generally required, thus minimizing the shifting and turning of special cars on a table. Furthermore, conflicting movements at the throat of the yard are avoided. It is important to note that the tunnel tracks from the New York Station are operated as two double-track lines, one (the 33d Street Tunnels) normally for Long Island Railroad trains, and the other (the 32d Street Tunnels) for movements to and from Sunnyside Yard. The Long Island Railroad trains, from the tunnels and from Long Island City, pass through the yard at a higher level than the yard tracks, and without grade crossings of any kind. In order, however, to give access to the yard from all tunnels and in the minimum distance, it was necessary to cross the west-bound 32d Street over the east-bound 33d Street Tunnel near the portals. Thus the yard may be entered at either end by the two east-bound tracks without grade crossings. A short distance east of the yard there is a jump-over connection and junction with the proposed New York Connecting Railway, a double-track line to connect

BUILDINGS FOR MOTIVE POWER FACILITIES

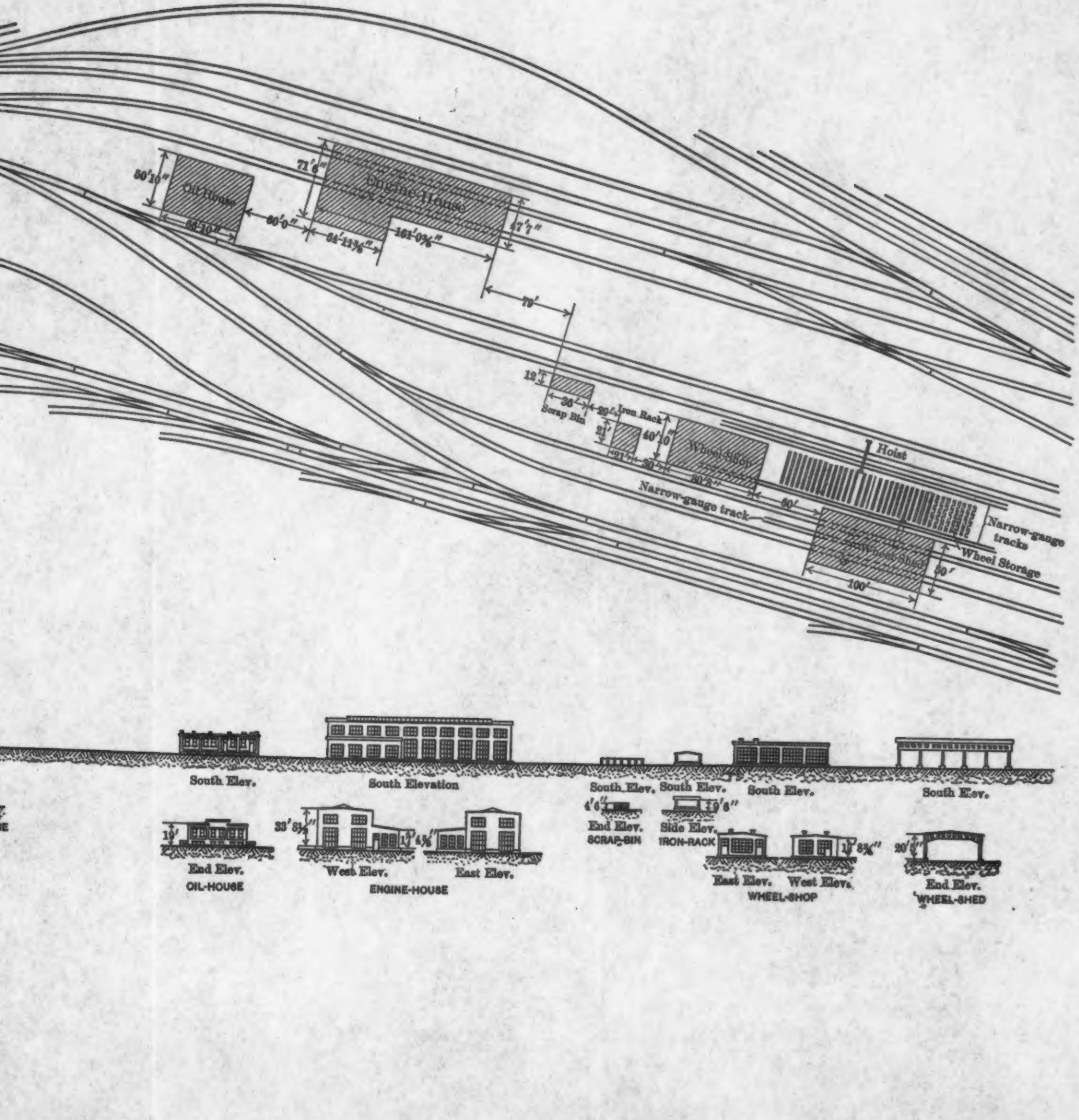
SUNNYSIDE YARD





Driveway to Honeywell Street Viaduct
Top of Slope
Top of Slope
Top of Slope
Boiler-House
Auxiliary Substation
100'10"
50'8"
10'6"
81'6"
Hard coal & Charcoal Bin
Tool House
Pipe Rack
21'
128'
180'10"
Battery-House
67'
102'
30'
Store-House
67'
162'2"
16'
25'
16'
25'
10'
Honeywell Street Viaduct
South Elev.
End Elev.
STORE-HOUSE
South Elev.
End Elev.
BATTERY-HOUSE
Side Elev.
PIPE ROCK
South Elevation
South Elev.
End Elev.
HARD COAL & CHARCOAL-BIN
Cross-Section
HONEYWELL ST. VIADUCT
TOOL-HOUSE
AUXILIARY SUBSTATION
&
BOILER HOUSE
200'
SUBSTATION
BOILER-HOUSE

PLATE XCIX.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1165.
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.



with the New York, New Haven and Hartford Railroad by a bridge over Hell Gate. The main freight connections of the Long Island Railroad to Long Island City pass around the yard to the north, and cross the yard approach by overhead bridges near the tunnel portals.

The main, or south, yard has an ultimate capacity for 861 cars, and the supplemental, or north, yard has a capacity of 526 cars; the present capacity, number of tracks, etc., are shown by the summary of statistics on page 322. The service buildings are between the north and south yards, as shown on Plate XCIX. Fig. 1, Plate C, is a view of the south yard looking eastward from Honeywell Street Viaduct; and Fig. 2, Plate C, is a view of the Sunnyside Yard buildings looking southeastward from the north yard.

The south yard, which is used for cleaning and making up trains, is provided with platforms between tracks for trucking purposes, and a complete piping system for air, water, and steam, as well as conduits and wiring for charging train-lighting batteries, all having connections for each car on each track. All tracks in both north and south yards are equipped with third-rail, so that electric motive power is available throughout for shifting trains. Fig. 1, Plate CI, is a view of the main tracks of the Long Island Railroad looking eastward from Thomson Avenue Viaduct, and showing the entrance to the yard. Fig. 2, Plate CI, is a view of Sunnyside Yard looking eastward from the tracks at the west end of the south yard.

Piping.—The piping and wiring systems are installed in a permanent and conveniently accessible manner. Thus, from the boiler-house and auxiliary power sub-station a cross pipe-tunnel 603 ft. long has been run at right angles to the main yard tracks, with openings to the inter-track spaces (see Fig. 11). Branching from this tunnel are concrete trenches, one between each alternate track, running the entire length of the tracks. In the walls of the tunnel and trenches are installed conduits for the battery-charging wires, the system being centrally operated from the sub-station; the tunnels and trenches also contain pipes for air, water, and steam. The trenches provide drainage for surface-water, and connect to the yard sewer system at suitable points.

Water Supply.—A complete local water supply is derived from wells sunk within the yard area, furnishing sufficient water for all the requirements of the yard, up to 1 000 000 gal. per day, and, in

addition, the requirements of the Long Island City power-house, the total being about 2 000 000 gal. per day. There are two wells, each about 30 ft. deep. They are operated by direct suction through pipes to the pumps in the basement of the boiler-house. The pumps supply the yard service piping system direct and, by a main line through the yard, a 250 000-gal. storage tank at Borden Avenue, near the tunnel portals, and thence to the Long Island City power-house.

Yard Lighting.—The general illumination of the yard is effected by forty-one 3 000-c.p. flaming-arc lamps of the long-burning type. These are mounted on steel poles from 200 to 350 ft. apart, having special reference to important local points. Direct current at 110 volts is supplied to the lamps from the battery-charging motor-generator sets in the auxiliary sub-station. The interior of the auxiliary power sub-station is shown on Fig. 1, Plate CII, and Fig. 2, Plate CII, shows the switch-board.

Yard Buildings.—The yard buildings have the following functions:

(*a*) A sand-house, equipped with sand-drying stoves, storage, and pneumatic elevating machinery for sanding locomotives.

Equipment:

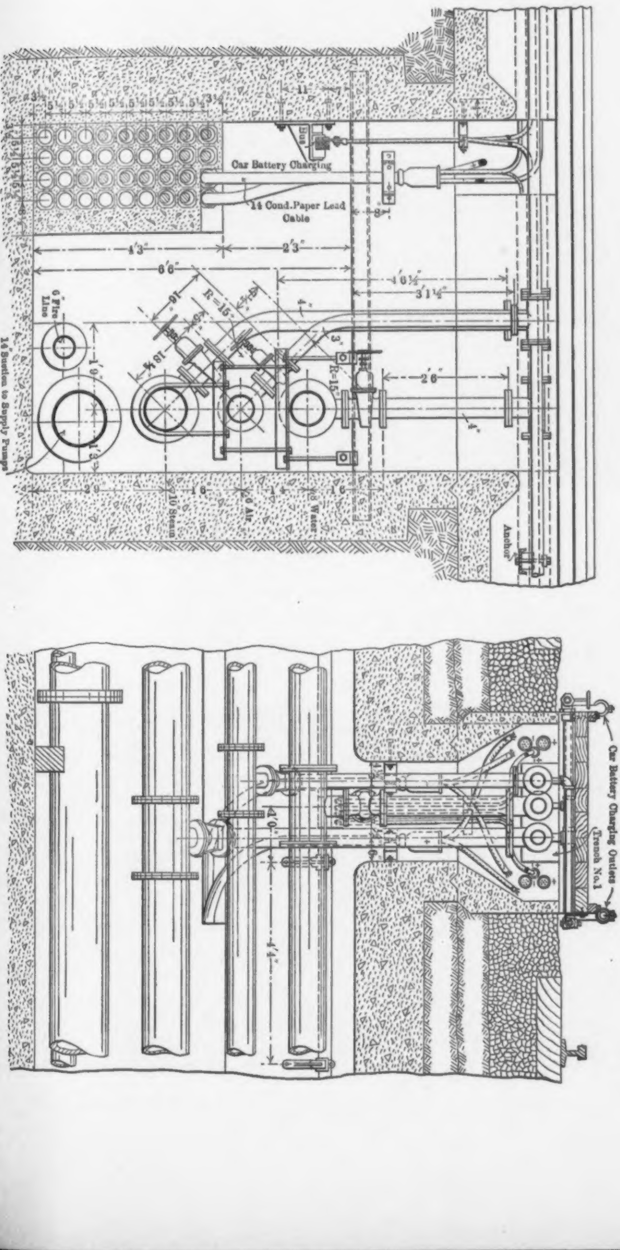
Concrete bins for the storage of 2 000 cu. ft. of wet sand and 550 cu. ft. of coal.
Two Pennsylvania Railroad standard sand dryers.
Two pneumatic dry sand tanks, 35 cu. ft. each,
Sand and air piping complete, and connections, with
Two gravity locomotive sanding tanks, 35 cu. ft. each.

(*b*) A carpet shed, equipped with benches and air cleaners for carpets.

Equipment:

Twelve carpet racks, each 12 by 12½ ft. and 2 ft. high, fitted with compressed air and vacuum nozzles for cleaning carpets.

(*c*) A commissary building containing separate provisions for the Railroad and the Pullman Company, for the storage of supplies for dining and sleeping cars, including a motor-driven refrigerating plant with cold boxes for perishable supplies. Also a bunk-room for Pullman employees.



TYPICAL SECTIONS OF MAIN PIPE TUNNEL, SUNNYSIDE YARD.

FIG. 11.

Equipment of P. R. R. Section:

Ten refrigerator boxes, ranging in capacity from 90 to 1 824 cu. ft., each equipped with direct-expansion ammonia coils for keeping meat, fish, poultry, fruit, ice cream, cheese, milk, butter, etc.

Two motor-driven refrigerating machines, 4 tons each.

One 3 000-lb. electric elevator.

One dumb-waiter.

Two 250-gal. water filters, each with two copper reservoirs for storing filtered water.

One two-oven range with heater, steam table, and kitchen equipment complete.

Three separate toilet-rooms, with hot and cold water and fixtures.

Four hose connections for fire, and 75 ft. of 2½-in. hose, with nozzles.

General commissary storage-rooms, wine-room, kitchen, silver-room, record storage room.

Clean- and soiled-linen rooms, linen-repair room.

Superintendent's and clerks' offices, kitchen, and porters' room.

Conductors' room, waiters' and cooks' room.

All rooms furnished with metal shelving and lockers.

Freight, team, and distributing platforms at each side of building.

Equipment of Pullman Section:

One general refrigerator box, about 500 cu. ft., with direct-expansion ammonia coils, and congealing tanks.

One motor-driven refrigerating machine, ½ ton capacity.

One 3 000-lb. electric elevator.

Three separate toilet-rooms, with hot and cold water and fixtures.

Four hose connections for fire, and 75 ft. of 2½-in. hose with nozzles.

General storage-rooms, soiled- and clean-linen rooms.

Linen-repair room, with air and electric sewing machines.

Carpet- and carpet-repair rooms.

Commissary-rooms, plumbers', carpenters', and testing-rooms.

Superintendent's, storekeeper's and foreman's rooms.

Porters' and cleaners' quarters and sleeping-rooms.

(*d*) A general store-house for the Railroad Company's stores (except oil), required for repairs in the yard and cars; also lavatories and closets for employees.

FIG. 1.—SUNNYSIDE YARD: VIEW OF SOUTH YARD, LOOKING EASTWARD FROM HONEYWELL STREET VIADUCT.

FIG. 2.—SUNNYSIDE YARD BUILDINGS: LOOKING SOUTHEASTWARD FROM NORTH YARD.

Equipment:

One 5 000-lb. electric elevator.

One 5 000-lb. P. R. R. dormant store-room scale, and portable store-room scales.

One stationary triple-valve test set, with four portable test sets complete.

Three separate toilet-rooms, with hot and cold water and fixtures.

Foreman's, storekeeper's and clerks' offices.

General store-rooms, carpet-rooms.

Air brake and pipe fitters', tin and carpenter shops.

Car cleaners' quarters and locker-rooms for both men and women.

All rooms furnished with metal shelving and lockers.

Three hose connections for fire, with 50 ft. of 2½-in. hose and nozzles.

Freight, team, and distributing platforms each side of building.

(*e*) A battery-repair house for car-lighting batteries, with a separate room for charging batteries and for spare batteries; also a distilling apparatus to supply pure water for refilling batteries.

Equipment:

Three 14-circuit switch-board panels, for battery charging.

One 17½-gal. per hour water still and reservoir.

One battery plate press and battery tools.

One motor-driven emery grinder and buffer.

One motor-driven sensitive drill press.

Two 1-ton chain falls and trolleys.

Two lead-covered battery cleaning benches with hot and cold water.

Battery assembling and charging benches.

Acid mixing and storage tanks, lead-lined.

Train lighting and repair-room, with benches and tools.

Lamp-frosting room, and general store-room.

Oxygen and hydrogen tanks.

(*f*) A boiler-house and auxiliary power sub-station (shown on the upper part of Plate XCIV), containing boilers with feed pumps, water heaters, etc., for supplying steam for all purposes in the yard; also pumps for water supply system and for fire service, air compressors for the air supply to the yard and to the signal system, and the auxiliary sub-station apparatus, as described under the heading "Auxiliary Sub-station." Fig. 12 is a cross-section of the boiler-house.

Equipment of Auxiliary Sub-station Section:

One 10-ton hand-power crane.
Two 1 500-cu. ft., two-stage, steam-driven, air compressors, with inter-coolers, reservoirs, traps, water-cooled after-cooler, and atmospheric after-cooler.
Office, toilet, and locker-rooms, and battery-room.
Three 250-kw., 110-220-volt, 3-wire, motor-generator sets for car battery charging, building lighting, and power.
Nine 125-kw., air-blast transformers.
Two 10 000-cu. ft. blowers for cooling transformers.
Thirty-four switch-board panels; 52 ultimately.
Eighteen car battery charging rheostats; 34 ultimately.

Equipment of Boiler-House Section:

Three 500-h.p. water-tube boilers, with chain-grate stokers.
One 20-ton, motor-driven, coal and ash-handling conveyor.
Four coal bunkers, 30 tons each.
One 20-ton motor-driven, coal crusher.
One steel, brick-lined, smoke-stack, 200 ft. high, 9 ft. in diameter at top.
Steel smoke flues, lined with reinforced magnesia and retort cement.
One 1 500-gal., boiler feed-water heater.
Two 150-gal., duplex, boiler feed pumps.
Soda ash system for treating boiler water.
Three 500-gal., compound, duplex-service water and fire pumps.
One 7½-h.p. steam engine, and one 10-h.p. motor for driving stoker.
One steam whistle, for fire protection.
One 40-gal. chemical engine.
One hose cart, and 1 000 ft. of 2½-in. hose.

(*g*) An oil-house, containing tanks for storage of the various kinds of oil needed for lubrication of cars and machinery, with measuring, cleaning, and pumping apparatus.

Equipment:

Complete metal equipment for waste, paints, and lamps.
Ten long-distance, self-measuring pumps.
Eleven short-stroke oil pumps.
Twenty-one oil-storage tanks.
One oil filter.
Two sponging tanks.
Complete oil-handling system.

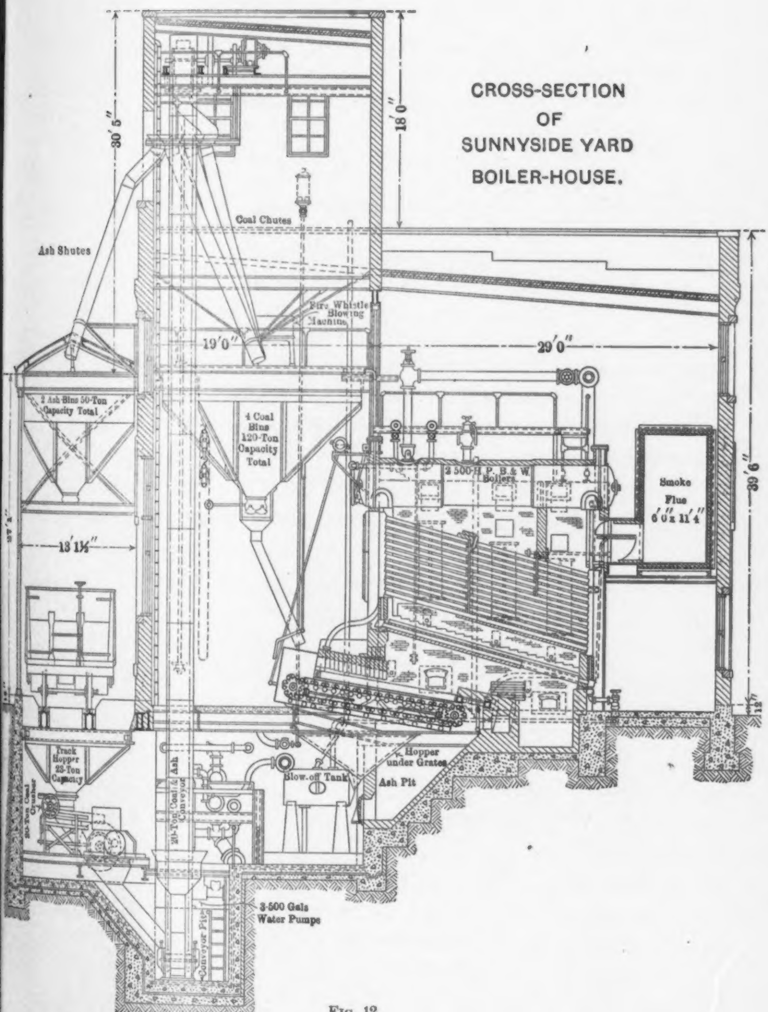

CROSS-SECTION
OF
SUNNYSIDE YARD
BOILER-HOUSE.
30' 5"
18' 0"
Coal Chutes
Ash Shutes
Fire Whistle Blowing Machine
19' 0"
29' 0"
2 Ash Bins 50-Ton Capacity Total
4 Coal Bins 120-Ton Capacity Total
2 500-H. P. B. & W. Boilers
Smoke Flue 6' 0" x 11' 4"
39' 6"
13' 1½"
Track Hopper 22-Ton Capacity
20-Ton Coal Crusher
20-Ton Coal & Ash Conveyor
Blow-off Tank
Hopper under Grates
Ash Pit
3-500 Gals Water Pumps
Conveyor Pit
12"

FIG. 12.

(*h*) An engine-house, with machine-shop, for housing electric locomotives during inspection. It is equipped with an electric traveling crane, pit jacks for dropping driving wheels, and machine tools for light repairs. Heavy locomotive repairs and general overhauling are to be done at the Meadows Shops of the Company.

Equipment:

- Offices, lockers and toilet-rooms with fixtures.
- Two inspection pits.
- One wheel pit, with pneumatic wheel jack and two air reservoirs.
- One 25-ton, three-motor, electric, traveling crane.
- Three lathes, one shaper, one boring machine, one framer, one rod and box press, one radial drill, one 2-spindle drill press, one power hack-saw, one grindstone, two emery grinders, one 2-ton crane and trolley, and all small tools.

(*i*) A wheel shed, provided with pits and air lifts for changing wheels on coaches, with a wheel-storage yard adjoining, equipped with an electric hoist.

Equipment:

- Two wheel pits, with two pneumatic wheel jacks and two air tanks.
- Two inspection pits.
- One 2-ton, electric hoist, trucks and track facilities, for handling wheels.

Yard Statistics.—The following additional statistics relate to the physical characteristics, operating quantities, etc., at Sunnyside Yard:

Extreme length of yard	8 815 ft.	
Extreme width of yard	1 625 "	
Area covered (3d Street to Laurel Hill Avenue)	192 acres.	
Present length of yard tracks (excluding main tracks)	25.72 miles.	
Length of main tracks in yard	11.09 "	
Ultimate length of yard tracks (excluding main tracks)	45.47 "	
	Present.	Ultimate.
Parallel tracks in south yard	34	77
" " " north "	12	42
Distance from Pennsylvania Station to east entrance of yard, *via* loop tracks	4.4 miles.	
Distance from west exit of yard to Pennsylvania Station	3.3 "	

	Present.	Ultimate.
Number of cars cared for daily in yard, for 1911 summer schedule	400	
Estimated ultimate daily capacity of yards, in cars cared for	1 000	
Standing room for cars in yard	503	1 387
Number of street viaducts over yard	5	
Total length of street viaducts	4 606 ft.	
Number of yard buildings	22	
Total length of between-track platforms	25 314 lin. ft.	
" " " umbrella sheds over platforms	2 798 " "	
Number of outlets at track for supplying cars with steam, water, air and electric battery charging.	800	

Miscellaneous General Facilities.

The following operating facilities apply to the Division as a whole, and may best be referred to under a general heading.

Drainage.—The disposal of the leakage and storm-water from the Station yard and the extensive system of tunnels presented an important problem. The conditions to be met are:

(*a*) The disposal of storm-water in the open portion of the yard, and at the tunnel portals;

(*b*) Provision against possible breakage in water mains or sewers, which might cause flooding of the tunnels and yards;

(*c*) The disposal of seepage from beneath the yard retaining walls, and of leakage through the land and river tunnel linings, and drainage into the portions of the land tunnels which were built without iron lining, through pipes inserted for that purpose.

In estimating storm-water, a rainfall which would produce a run-off of 3 in. per hour was taken as the maximum. In the yard the estimate of seepage was based on experience under similar conditions; in the case of the tunnels, actual figures were obtained after the completion of the tunnel system. The likelihood of breakage in water mains or sewers in the streets around the yard and at the tunnel portals was carefully weighed, having regard to local conditions, and it was concluded that, given a reasonable capacity in the various sumps and pumps, which are necesary to care for the disposal of seepage and storm-water in the different sections of the tunnels, there would be sufficient reserve to care for any probable emergency conditions result-

ing from pipe breakages prior to the time when the water could be turned off. Compared with the possible quantity of storm-water, it has been found that the seepage to be cared for is quite small. The average seepage for each of the different sections, at the present time, is given in Table 7; these averages, however, may vary somewhat.

TABLE 7.—TUNNEL AND YARD SEEPAGE.

	Total gallons per minute.	Gallons per foot of tunnel per 24 hours.
EAST RIVER SECTION:		
Long Island City Shaft, Tunnels 1 and 2	23	4.2
" " " " " 3 " 4	52	9.7
River Tunnels, Lines 1 and 2	0.93	0.17
" " " 3 " 4	0.42	0.7
CROSS-TOWN SECTION:		
First Avenue Shaft, Lines 1 and 2	52	6.7
" " " " 3 " 4	51	6.6
STATION YARD AREA:		
Seventh Avenue Sump	40	......
Service Plant Sump	15	......
Ninth Avenue Sump	80	......
Tenth Avenue Sump	40	......
Eleventh Avenue Shaft	20	......
NORTH RIVER SECTION:		
River Tunnels (2)	0.8	0.085
Bergen Hill Tunnels (2)	70	8.428

NOTE.—In this paper the East River Tunnels are designated by numbers, instead of by the letters used in other papers; thus, as now established, Tunnel "D" becomes "1," "C" becomes "2," "B" becomes "3," and "A" becomes "4."

Pumping.—Seventeen pump sumps are provided for the system, from Hackensack Portal to Sunnyside Yard; their capacities and locations are given in Table 8. Fig. 2, Plate XCIII, is a view of the interior of the Ninth Avenue sump, showing the vertical-shaft motors for the pumps. All pumps, except those at the lowest point in each of the six subaqueous tunnels, are of the submerged centrifugal type, primed at all times (see Fig. 13); they are set horizontally, and driven by vertical shafts from electric motors located in rooms above the sumps. The motors operate by three-phase, alternating, 60-cycle current at 440 volts, supplied, through transformers from the 11 000-volt circuits for lighting and auxiliary power, from the Service Plant. Each motor is controlled by a separate float-switch which starts and stops the pumps at certain pre-determined levels of water in the sump. Under normal conditions, only one sump pump operates, but the float-switch of the second pump is set so that the second pump will start also, in case the quantity of incoming water is so great that the level keeps

FIG. 1.—MAIN AND LOOP TRACKS, L. I. R. R., SUNNYSIDE YARD, LOOKING EASTWARD FROM THOMSON AVENUE VIADUCT.

FIG. 2.—SUNNYSIDE YARD: LOOKING EASTWARD FROM TRACKS OF L. I. R. R. AT WEST END OF SOUTH YARD.

rising after the first pump is started. The floats being adjustable, the starting levels of the pumps are interchanged at certain intervals of time to insure all pumps being in proper operating condition. The air-driven pumps in the subaqueous tunnels have similar arrangements, except that the float operates a special air-valve instead of an electric switch.

TABLE 8.—Drainage and Pumping System.

Sump No.	Location.	Capacity of sump, in gallons.	Number of pumps.	Capacity of pumps, in gallons per minute.	Horse-power of motors.	Speed, in revolutions per minute.
1..	Sunnyside Portal, Tunnel No. 4....	26 000	1	500	7.5	1 120
2..	Sunnyside Portal, Tunnel No. 2.....	13 000	1	250	5.0	1 120
3..	Sunnyside Portal, Tunnels Nos. 1 and 3....	58 000	2	500	10.0	1 120
4..	Long Island City Shaft, Tunnels Nos. 3 and 4....	59 000	1	100	7.5	1 700
			1	1 000	40.0	1 120
5..	Long Island City Shaft, Tunnels Nos. 1 and 2....	59 000	1	100	7.5	1 700
			1	500	20.0	1 700
6..	1 000 ft. east of First Avenue Shaft, between Tunnels Nos. 3 and 4.....	16 000	2	100	6½ by 5 by 10 in.	42
7..	1 000 ft. east of First Avenue Shaft, between Tunnels Nos. 1 and 2.....	16 000	2	100	6½ by 5 by 10 in.	42
8..	First Avenue Shaft, Tunnels Nos. 3 and 4....	54 000	2	100	7.5	1 700
9..	First Avenue Shaft, Tunnels Nos. 1 and 2....	54 000	2	200	10.0	1 700
10..	Pennsylvania Station, Under tracks east of Platform No. 2....	31 000	2	2 500	75.0	690
11..	Under 31st Street, Pennsylvania Station Service Plant....	20 000	2	500	15.0	850
12..	Under Yard "C" at Ninth Avenue, Pennsylvania Station....	100 000	2	7 250	240.0	580
			1	250	15.0	1 700
13..	South Side, Tenth Avenue Portal...	37 000	2	4 100	100.0	690
			1	250	15.0	1 700
14..	Eleventh Avenue Shaft....	10 000	1	100	7.5	1 700
		38 000	1	1 000	30.0	1 120
15..	2 200 ft. east of Weehawken Shaft, in west-bound tunnel....	500	1	50	4½ by 4 by 8 in.	50
			1	250	10 by 8 by 12 in.	40
16..	2 200 ft. east of Weehawken Shaft, in east-bound tunnel....	500	1	50	4½ by 4 by 8 in.	50
			1	250	10 by 8 by 12 in.	40
17..	Weehawken Shaft....	37 000	2	250	15.0	1 700

The discharge from the centrifugal pumps is piped to the street surface and thence to the nearest sewer. The discharge pipe from the air-driven pumps is carried on the tunnel bench to the nearest shaft; thence to the surface, and to the nearest sewer.

The pumps in the subaqueous tunnels are of the duplex, air-driven piston type, operated from the compressed-air mains in the tunnels. This type was adopted, rather than the electrically-driven type, to insure operation in case the pump chamber became flooded. They are of small capacity only, as the quantity of water to be handled is not great.

Fire Protection in Station Yard.—The large open area of the Station Yard and the superior fire-proof construction of the buildings furnish a very important fire barrier in the heart of New York City. This break extends from Seventh to Tenth Avenues, a distance of 2 800 ft.

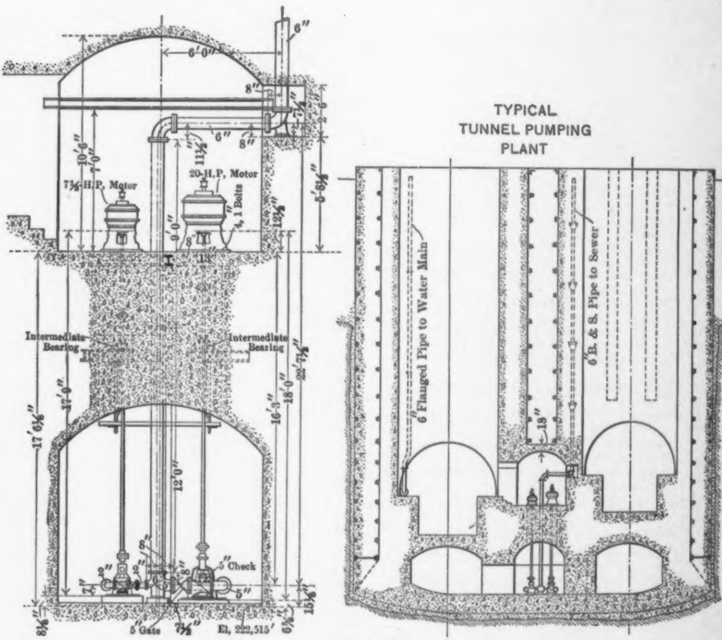


FIG. 13.

The character of the buildings would not seem to require elaborate fire protection, the Station being of unusually non-combustible construction, yet it was thought desirable to prevent any possibility of even small fires starting a panic among the passengers, in the building or in the trains under it, and, furthermore, it was desired to protect the terminal as a whole from the consequences of fire in buildings on private property surrounding it. Therefore, a very complete fire protection system was installed, both in the building and yard.

The necessary water supply is from two pumps in the 31st Street Service Plant, the fire piping system consisting of two closed loops,

one supplying the Station Building and the other the yard at the track level. These loops are of 10-in. wrought-steel pipe, the risers being of galvanized steel. The mains are carried around the building in the pipe gallery or basement covering the entire area under the public rooms, and risers are placed in special vertical chambers or flues, where they are readily accessible. The yard system leaves the Service Plant by the subways under the tracks, from which the pipes are tapped at various points under the platforms; or along the marginal retaining walls. About 3 miles of piping, varying in size from 6 to 2½ in. in diameter, were required.

There are sixteen 4-in. stand-pipes in the main building, with 83 hose connections. At the track level there are 23 hose connections on the station platforms and 12 fire-hydrants in the yard west of them. The hose equipment for the yard is stored in convenient form for quick handling in the various yard buildings, and the platform hose, in 100-ft. lengths, is coiled in special housings at the connections on the columns supporting the buildings. The building hose connections are provided also with 100-ft. lengths of 2½-in. linen hose suspended from racks, and on the roof 100 ft. of hose is stored in two centrally located hose houses. Six Siamese connections are provided at the building corners to permit the city fire engines to pump into the stand-pipe system. In addition, there is a 60-gal. chemical engine with a 500-ft. reel carriage in the baggage passageway under Seventh Avenue. The total length of hose equipment is about 10 000 ft.

The Service Plant is provided with a 4-in. loop supplying eleven hose connections and five monitor connections on the roof, for protection against fire in adjacent buildings.

Hand chemical extinguishers have been provided at various places in the Station, in all buildings in the yard, and on certain of the platforms. There are 131 of these extinguishers.

A complete local system of fire-alarm boxes covers the Station, Service Plant, Station Yard, and Sunnyside Yard. In the Station Yard there are 20 boxes located in central positions in the buildings and yard. There are also two city fire-alarm boxes in the Station Building, and these have been connected with the general city fire-alarm system. This system operates in a closed circuit, wired in loops of ten stations each, recording on three gongs, one under the main concourse, the second in the Yard Master's office, and the third

in the engine-room of the Service Plant. In addition, there are a number of punch registers and tap bells in the offices of the various station officials. The boxes are of the non-interfering, successive type of the Pennsylvania Railroad standard design. An alarm will be responded to by a special fire-brigade organization in which the men are divided into hose-wagon, chemical-engine, and stand-pipe gangs; and, in addition, men are specially designated to handle fire extinguishers.

Fire Protection in Sunnyside Yard.—In the sub-station in Sunnyside Yard there are three 500-gal. pumps; one of these is used for supplying water for cleaning cars and other yard purposes; one supplies the fire mains, maintaining a pressure of about 80 lb., and the third is held in reserve. There are fire lines throughout the yard, with the necessary hydrant connections, and these fire lines are entirely distinct from other water lines. There are fourteen fire-alarm boxes throughout the yard, and they operate visual indicators in the hose-houses and in the various offices in the buildings, and also the whistle-blowing machine. Two hose carriages are provided at central points for the fire brigade. Connection with the city fire-alarm system is made through a box installed for the purpose in the auxiliary sub-station.

Yard Lighting.

Station.—The open portion of the Station Yard is lighted by 18 flaming-arc lamps, supported about 40 ft. above the tracks by brackets from the retaining walls, bridges, and certain other structures, so as to give a reasonably even distribution of light throughout. These lamps operate on alternating current at 240 volts pressure, distributed from the Station lighting mains.

Sunnyside Yard.—The general illumination of the yard is effected by forty-one 3 000-c.p. flaming-arc lamps of the long-burning type, the same as in the Station Yard. These lamps are mounted on steel poles from 200 to 350 ft. apart, having special reference to important local points. Direct current at 110 volts is supplied to the lamps from the battery-charging motor-generator sets in the auxiliary sub-station of the yard.

Manhattan Transfer.—This yard is similarly lighted by 13 flaming-arc lamps, mounted on concrete poles. These lamps operate by 220-volt 60-cycle, alternating current, furnished through transformers from the 2 200-volt signal mains, and located in Signal Cabins "N" and "S".

FIG. 1.—INTERIOR OF AUXILIARY POWER SUB-STATION, SUNNYSIDE YARD.

FIG. 2.—BATTERY-CHARGING SWITCH-BOARD, SUNNYSIDE YARD AUXILIARY POWER SUB-STATION.

Snow-Melting System.

A supply of hydro-carbon oil is carried in tanks in each of the three yards, and applied, as needed, to the switches, frogs, etc. It is set on fire at the points in question, and this furnishes sufficient local heat to melt quickly any accumulation of snow and ice. In Sunnyside Yard two 4 000-gal. storage tanks are placed underground in a remote portion of the yard, and from them the oil is piped to central points near the main switch systems at the ends of the yard. At these points the oil is drawn into small cans and thus conveyed to the switches for local application. In the Station yard, there is one 750-gal. tank west of Ninth Avenue; it receives its supply of oil through a pipe to the tank, by wagon delivery in 31st Street. From the tank, local distribution in the yard is effected in small safety cans. At Manhattan Transfer, one 1 000-gal. tank is located underground at the west end of the yard. Delivery is by a short run of piping to a central point, and thence to the switches by hand safety cans.

Electric Power System.

Electric power is needed for moving trains over the Division, and for a variety of other purposes. The requirements will hereinafter be referred to as for traction and for auxiliary purposes. Both kinds can obviously be generated most economically at a central point, and distributed over the division, by suitable transmission and distributing cable systems, to local points or sub-stations for transformation and control.

The provisions for traction power are of primary importance in the design and location of a central plant, and yet the provisions for auxiliary power must be comprehensive and complete, in order to insure uninterrupted operation of the Division as a whole. This latter power serves the important operating purposes of motive power for signals, lighting the Station, tunnels, and yards, the operation of motors for various purposes about the Station, and for the ventilation and drainage of the tunnels and yard; also, for secondary purposes, in charging car batteries, as well as batteries for the telephone and telegraph system, and baggage trucks.

Selection of Traction System.—As the use of a tunnel entrance into New York City was predicated upon the use of electric traction, a statement of the conditions to be met and of the investigations leading up to the determination of a proper system, and a description

of its general characteristics, will be of interest. In 1902, when the terminal work was commenced, there were few practical examples of heavy electric traction in existence, and none of the magnitude and complexity of the proposed terminal operation. As it was realized that much experimental work would be necessary to perfect the details, a complete programme to this end was laid out some years in advance of the time when the actual installation of apparatus would be required.

Electrification of a portion of the Long Island Railroad was begun as a separate matter at about the same time, the system adopted being the so-called "third-rail," or "direct-current." This system is more properly termed the "A.C.-D.C.," that is, high-tension alternating current is generated at the power-house and transmitted as such to sub-stations, where it is lowered in potential and converted into direct current to be fed into the third-rail system. This system was practically the only one in a sufficiently advanced state of development to warrant its adoption for heavy work at the date in question. The "single-phase" alternating-current system was offered later as a possible advance in the art, and was adopted on important work, notably the New York, New Haven and Hartford Railroad from its New York connection to Stamford, Conn. This development, therefore, demanded an investigation of the relative merits of the two systems for the New York Terminal, and to this end the President appointed, as a Special Committee, the heads of the Motive Power Departments of the Pennsylvania Lines East and West, and of the Long Island Railroad, to co-operate with and report to the writer, in determining the system to be used. A systematic plan was formulated for investigating the practical behavior of the two systems, and, in order to try out certain features of the single-phase system in its application to the tunnel conditions, an experimental line 5 miles in length was constructed on a branch of the Long Island Railroad. On this line an equivalent of a tunnel section was installed and equipped with a high-tension overhead conductor; various contact devices designed for sparkless collection of current were tried; and a multiple-unit motor-car equipment and a special type of A.C. locomotive were tested. The test car and locomotive, as well as much other apparatus, were kindly supplied by the Westinghouse Electric Company.

The results of the tests cannot be given here in detail, but they were reassuring in some respects and disappointing in others. In the

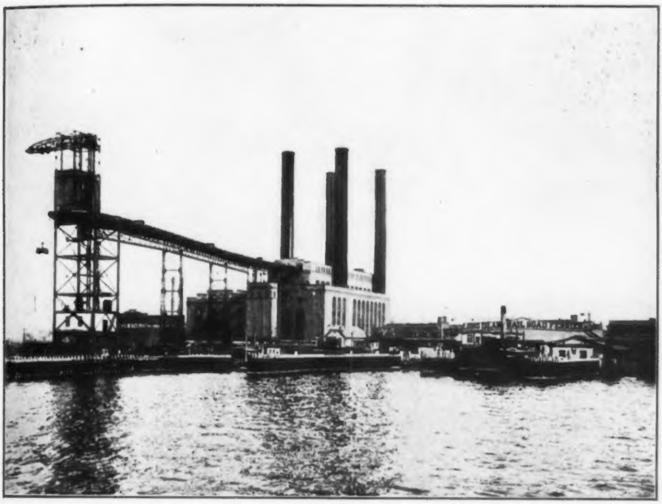


FIG. 1.—LONG ISLAND CITY POWER-HOUSE.

FIG. 2.—ENGINE-ROOM, LONG ISLAND CITY POWER-HOUSE. 3 000-KW. AUXILIARY POWER GENERATORS IN FOREGROUND.

main, they demonstrated the need of considerable further experimental work to adapt the system to the tunnel and yard conditions. The recommendation of the committee was for the adoption of the "Direct Current" (A.C.-D.C.) system, interchangeable with that used on the Long Island Railroad, for the following main and important reasons:

First, reliability, from the start; second, freedom from complication in interchange with the Long Island traction system and the Newark Rapid Transit line through the Hudson and Manhattan tubes into Church Street, New York; and third, less expenditure involved at present and for some time to come. The above reasons, it should be remembered, apply only to this special installation. No broad generalization is intended for other traction projects, where local conditions must govern.

Load Conditions.—The load conditions include both traction and auxiliary power; and, in case of traction power, the requirements for the Long Island Railroad. Considering all these requirements, the load center was at a point adjoining the railway lines in Long Island City and not far from the water-front of the East River. It was at first proposed to establish two power-houses, each to relay the other, under which plan the location of one house would fall on the New York side of the Hudson River and the other at a point not far from Jamaica. Neither of these locations was altogether suitable, on account of difficulty in procuring the site in the first mentioned place, and the absence of water for condensing purposes in the other. Furthermore, it was found that, in dividing the load between two plants, the call on neither one would be sufficient to give reasonable economy in operation; the relaying feature, therefore, of the two power-houses, in the case of the disablement of one of them, was the only important point in favor of such a plan. Experience has shown that a properly designed plant, provided with suitable safeguards against a general breakdown from an accident to a part of the machinery, and with duplicate cable connections to the outside, can be depended on to furnish an uninterrupted supply of power, except for very infrequent and short interruptions, in which cases power supply can be restored in less time than it would take to obtain full relief from a second plant, especially where both are only of moderate size. Furthermore, in a great electric traction center, such as the City of New York, it is possible to establish emergency connections with other power-plants. In view of these

considerations, therefore, it was determined to establish only one power-house for present operation, and to equip it to supply power for both traction and auxiliary purposes.

For an emergency supply of power for traction, it has been arranged to connect the general traction system at three different points with the power-plants of three companies, namely, the Public Service Corporation, in New Jersey, the Hudson and Manhattan Railroad Company, in New York, and the New York and Queens County Railway, in Long Island City.

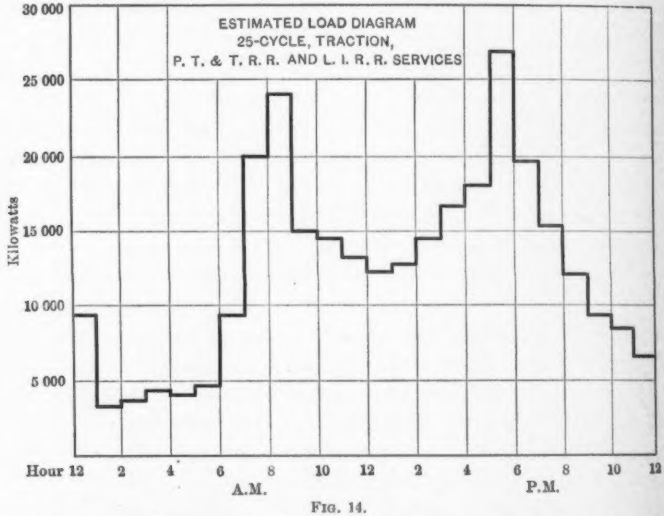
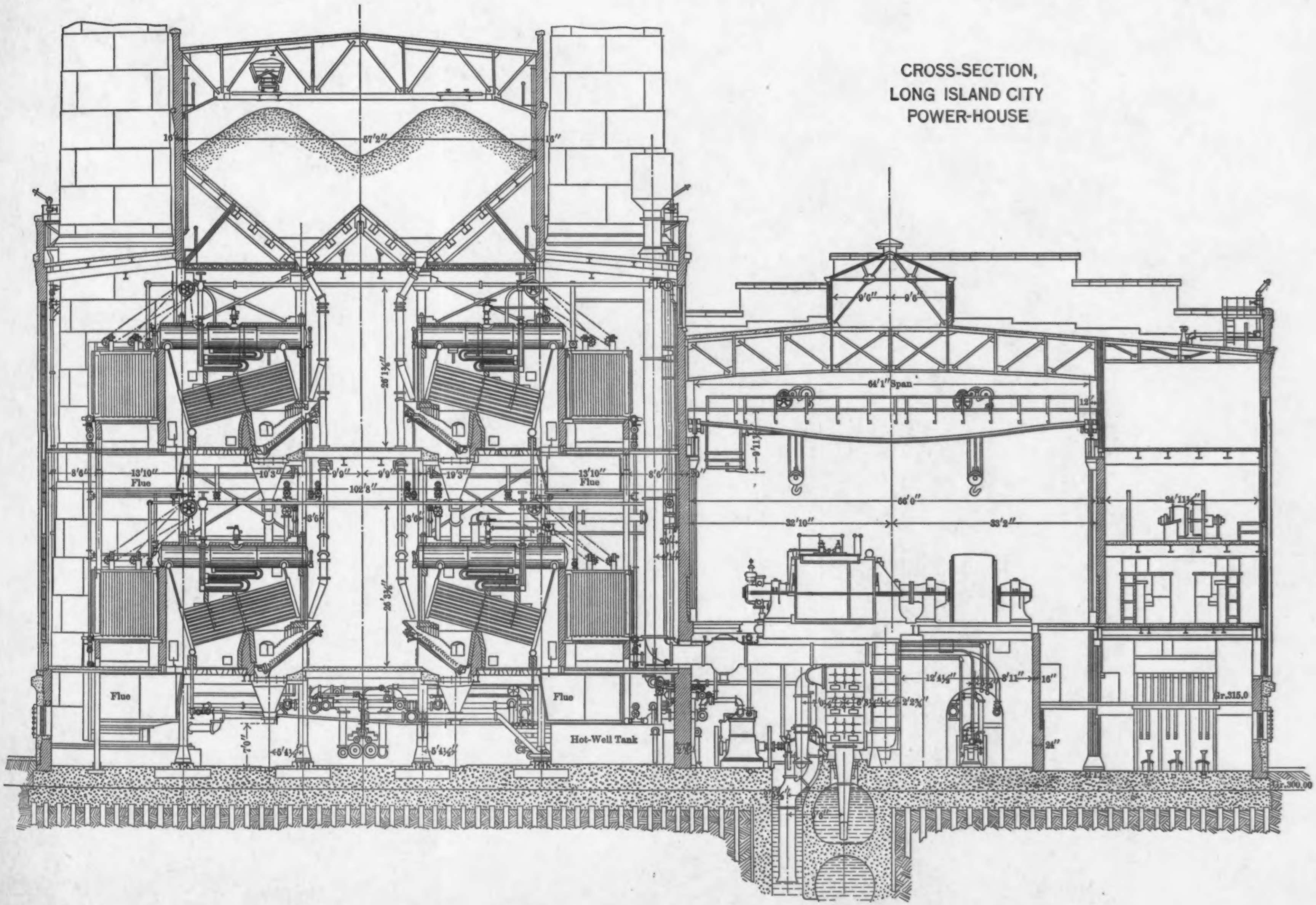


FIG. 14.

As an emergency supply for auxiliary power purposes, the Service Plant, described elsewhere, is equipped with generating apparatus capable of supplying all the auxiliary power required for the entire system. The combined load conditions for all services are shown in the curves, Figs. 14 and 15; and the central power-plant has been designed to care for these loads with sufficient reserve for ordinary emergencies and a limited amount of spare capacity in the building for growth of traffic; but it has not been designed to take care of a general extension of the electric traction system to other Pennsylvania lines. When such extensions are made, additions can be made to the present power-house building, or, preferably, a new power-house can be erected on the New Jersey side.

CROSS-SECTION,
LONG ISLAND CITY
POWER-HOUSE



Long Island City Power-House.

Location.—The Long Island City Power-house, Fig. 1, Plate CIII, is on the East River, in Long Island City, a location nearly central to the present load conditions, close to the tunnel lines, and requiring only short cable connections to the tunnels, and thence over the Terminal Division.

The building of this plant was undertaken some years prior to the completion of the tunnel system, in order to care for the electrified lines of the Long Island Railroad into the City of Brooklyn, follow-

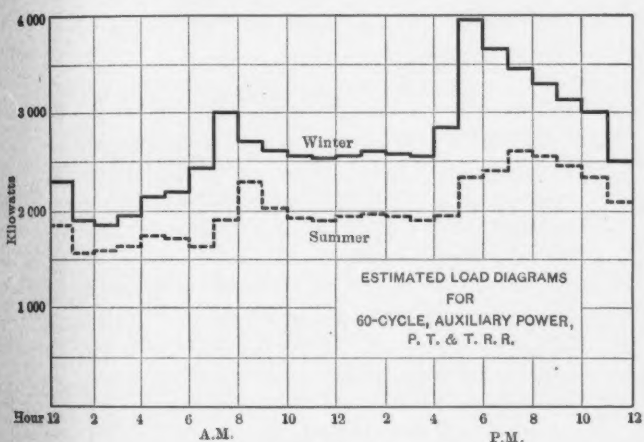


FIG. 15.

ing the completion of the Atlantic Avenue Improvement of that road; and power from it for this operation has been furnished since 1905. Recently, additional equipment has been added for the tunnel operation.

Foundations.—The site was partly under water, with solid rock at a depth of from 35 to 60 ft. below high water, the intermediate strata being of clay, sand, and gravel. It was decided to use a pile foundation, overlaid with a monolithic concrete base. The piles were spaced at 2-ft. centers, on an average, and carry a load of 12 tons each; 9 100 piles in all were used. They were cut off below the extreme low-water line and overlaid with a concrete mattress 6 ft. 6 in. thick, in which about 18 000 cu. yd. of concrete were required.

Building.—The building is a steel-frame structure with brick curtain-walls. It is of fire-proof construction throughout, with windows of wire glass in metal frames. The boiler-room is double-decked; the engine-room adjoins, with the switching galleries at the side (see Plates CIV and CV). The coal is stored above the boiler-room in pockets having 5 200 tons capacity. The bunkers are of reinforced concrete, with partitions dividing the storage space. There are four stacks, carried from the base independently of the house. They are 233 ft. high above the grates of the upper tier of boilers, or 275 ft. from the base, with an interior diameter of 17 ft. They are of steel, brick-lined to the top. The coal-handling plant is designed to deliver coal into the power-house pockets from barges at the water-front dock, although delivery from cars may be made if required.

Fire Protection.—A complete fire protection system has been provided, chiefly because of the possible hazard from adjoining buildings. The stand-pipe system consists of 6-in. risers at the corners of the building connecting to seven hydrants on the roof with monitor nozzles. There are also two nozzles on the bridge of the coal tower and two at the extreme end to protect the dock property. Six Siamese steamer connections are provided at the street level, and may be used for hose connections or for supplying the stand-pipe system from the city fire department steamers. In the basement there are two duplex fire pumps, each having a capacity of 1 000 gal. per min., each with a 10-in. suction from the river, and delivering into the header for the building supply. The coal bunkers are provided with pipe connections for flooding in case of necessity.

Coal Handling.—A hoisting tower on the deck is connected with the house by a bridge, 500 ft. in length, with its deck 107 ft. above the dock; the tower is 170 ft. high. Coal is hoisted in 2-ton self-loading buckets, at a speed of 1 000 ft. per min., to the weighing and crushing machinery in the tower, from which it is delivered into the cars of a cable railway on the bridge. The machinery is capable of unloading and delivering into the bins 150 tons per hour, and, for the past three years, the average cost of handling, for labor and maintenance, has been 5.40 cents per ton. Ashes are delivered into a bin outside of the building and over a railroad track, by a telpherage system which hoists and transports the ash cars from the boiler-room basement.

PLATE CV.
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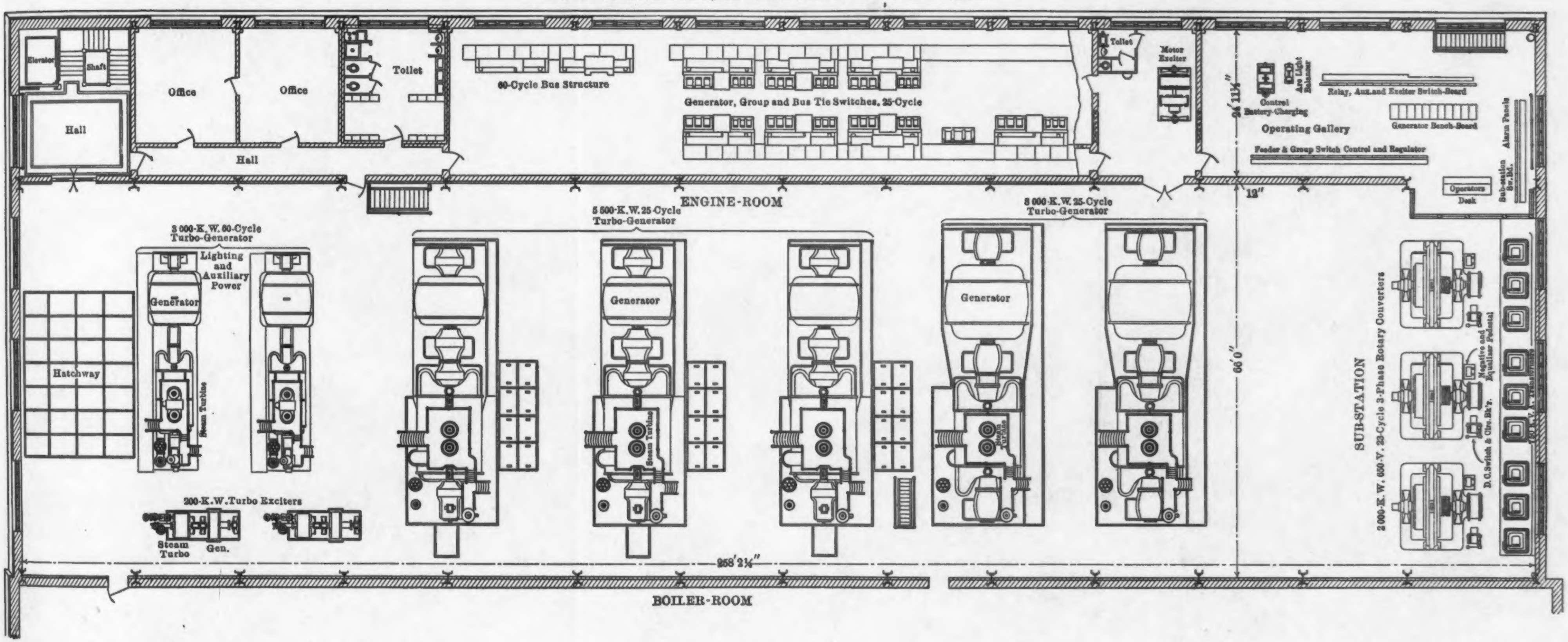
PLAN OF ENGINE-ROOM, LONG ISLAND CITY POWER-HOUSE.



Boilers.—The present equipment consists of thirty-two boilers, each of 564 h.p., sixteen on each floor, of Babcock and Wilcox water-tube type, built for a working pressure of 200 lb. per sq. in., and fitted with superheaters for 150 lb. of superheat, and mechanical stokers. At the rear of the boilers are placed the economizers, one for each two batteries of boilers.

Turbo-Generators.—Westinghouse-Parsons steam turbines drive directly the three-phase, A.C., 11 000-volt, 25-cycle, revolving-field generators. The equipment initially installed to operate the Long Island Railroad traction system consisted of three units of 5 500 kw. each, at 750 rev. per min. To care for the increase of load from the Terminal operation, two units were recently added. These are double-flow turbines, direct-coupled to 11 000-volt, three-phase generators of 8 000 kw. capacity at 750 rev. per min.

Two 3 000-kw. turbo-generators of the same type (Fig. 2, Plate CIII), generating three-phase current at 11 000 volts and 60 cycles, have been provided for auxiliary power purposes; these units relay similar units in the 31st Street Service Plant, and are used either for emergency, or in summer when exhaust steam from the latter plant is not needed for heating the Station Building. There is space in the present building for an additional unit of 8 000 kw., with the necessary boilers and accessories.

Condensers.—All the turbines are condensing. The condensers for the three original 5 500-kw. units are of the "surface" type, and were selected in order to reclaim the boiler feed-water, as water had to be purchased and was quite expensive. Injection water is obtained from the East River. As was expected, the maintenance cost of these surface condensers proved to be rather high, and, when the additional units were installed, an opportunity to use "jet" condensers economically was afforded by the discovery of an ample supply of good water in Sunnyside Yard. This supply is estimated to be sufficient to care for all power-house boiler feed-water as well as the yard requirements. The four new units were provided with jet condensers of the Le Blanc type.

Exciters.—Three separate sources of current are provided, for exciting the fields of the generators: these consist of, two steam-driven units, one motor-driven unit, and a storage battery.

Switching Apparatus.—The switching apparatus is in a separately-

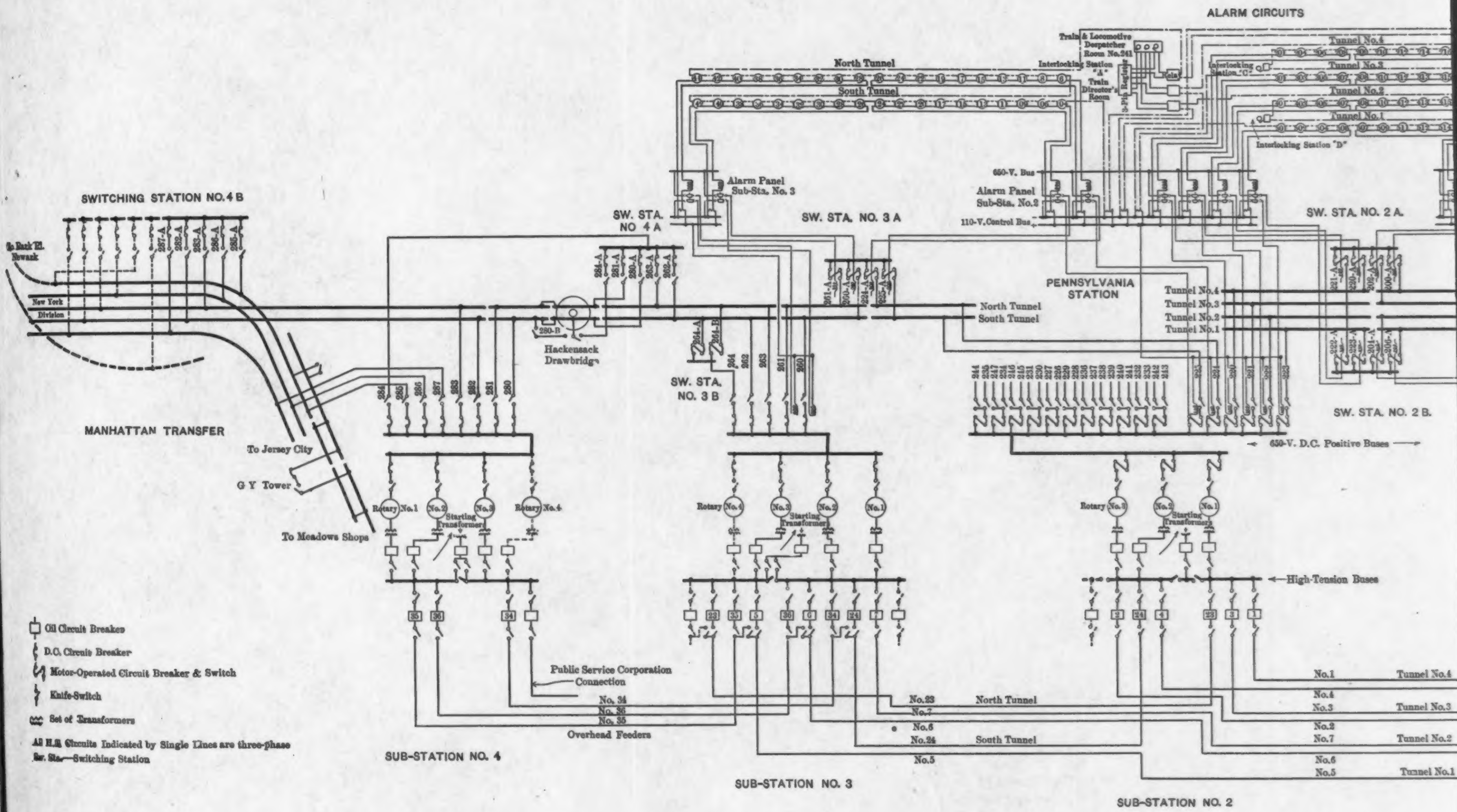
housed gallery of three floors and a basement. The various cables are brought out of the conduits at the basement floor in cubicles to the switches on the floor above. Transformers for lighting purposes and for the motor-driven exciter are also located on the basement floor, as well as the storage battery for emergency excitation and for operating the electrically-controlled switch-board.

On the first floor are mounted the main generator-switches and the individual feeder-switches. On the second floor are the selector-switches to the generators, and the selector-group-switches for the feeders, also the main bus-bars and tie-switches for the same. On the third floor are installed the main controlling switch-board panels, instruments, etc., for controlling all generator-feeder- and group-switches. This floor also contains the motor-driven exciter and battery-charging booster, and at one end there is a separate control board for controlling the sub-station machinery. Near the main switches a glass-enclosed bay is provided, from which is afforded a full view of the engine-room containing the turbo-generators and rotary converters.

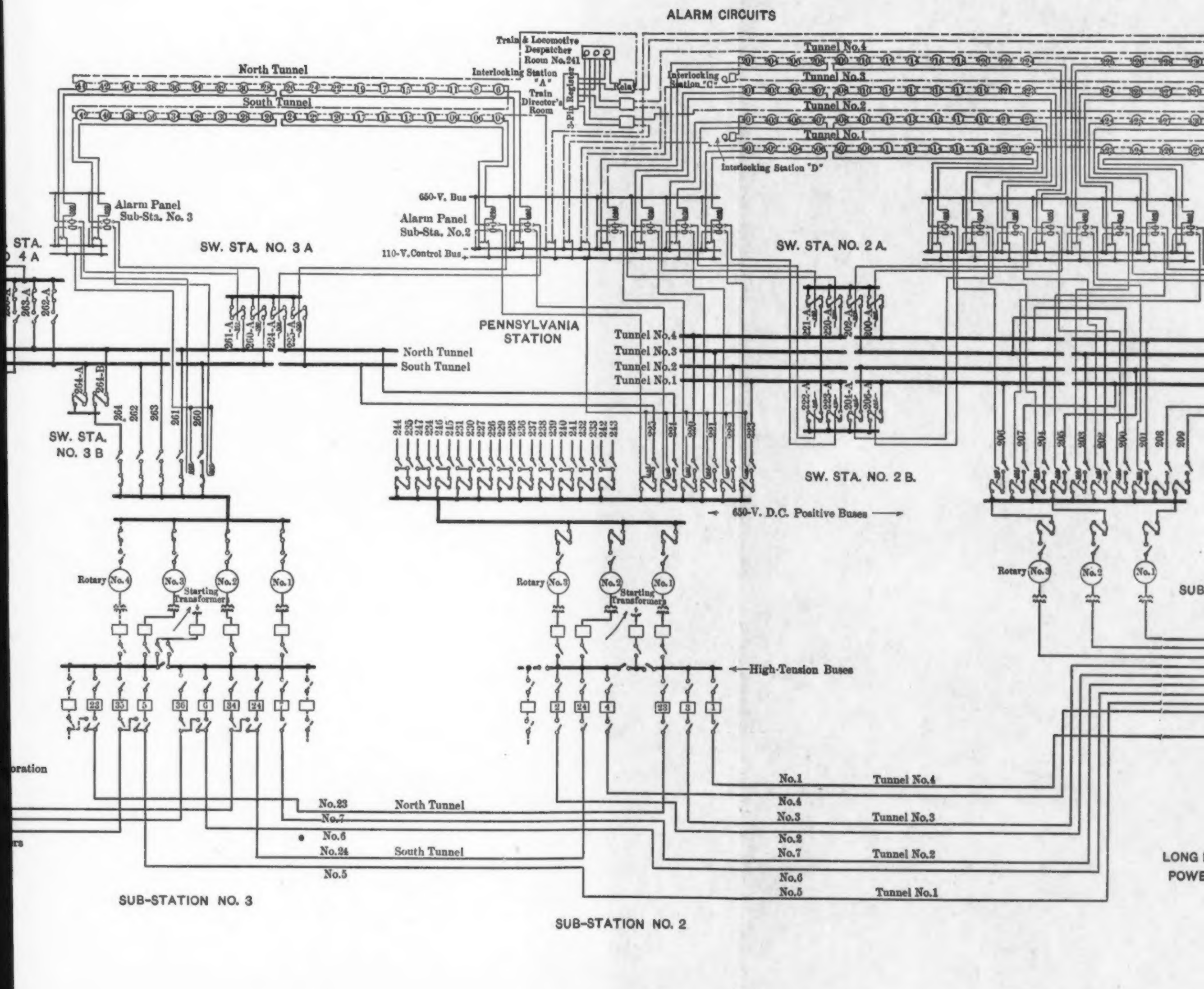
The switching arrangement consists in providing an open-ring bus structure, divided into three sections, controllable by the operator through oil-switches. The three 5 500-kw. generators and all the switch feeder groups are arranged to connect to either of the two end loops, and two 8 000-kw. generators are connected to the middle sections of the ring.

All feeders are arranged in groups, usually three feeders per group, and connected through the oil circuit-breakers to group bus-bars, which in turn are connected to the main bus-bars through selector-group-switches. All the remote-controlled switches and circuit-breakers are of the oil type, having the contacts immersed in the oil chamber at all times, which effectively extinguishes an arc when the switch is broken under load.

The feeder cables which lead to the Long Island Railroad, where the transmission is in the main overhead, and where short-circuits are consequently more apt to occur, are provided with auxiliary switches having resistance contact, which, during the opening of the switch, serves first to cut resistance in series, thus reducing the current before the actual break occurs. The neutral points of the generator winding are connected to a neutral bus-bar, which is grounded through a suit-



ALARM CIRCUITS
Train & Locomotive Despatcher Room No. 241
Interlocking Station "A"
Train Director's Room
Relay
Interlocking Station "C"
Interlocking Station "D"
Tunnel No. 4
Tunnel No. 3
Tunnel No. 2
Tunnel No. 1
North Tunnel
South Tunnel
Alarm Panel Sub-Sta. No. 3
Alarm Panel Sub-Sta. No. 2
650-V. Bus
110-V. Control Bus
SWITCHING STATION NO. 4 B
SW. STA. NO. 4 A
SW. STA. NO. 3 A
SW. STA. NO. 3 B
SW. STA. NO. 2 A.
SW. STA. NO. 2 B.
PENNSYLVANIA STATION
Hackensack Drawbridge
To Jersey City
G Y Tower
To Meadows Shops
MANHATTAN TRANSFER
New York Division
650-V. D.C. Positive Buses
High-Tension Buses
Rotary No. 1
Rotary No. 4
Rotary No. 3
Starting Transformers
Public Service Corporation Connection
No. 34
No. 36
No. 35
Overhead Feeders
No. 23
No. 7
No. 6
No. 24
No. 5
No. 1
No. 4
No. 3
No. 2
SUB-STATION NO. 4
SUB-STATION NO. 3
SUB-STATION NO. 2
Oil Circuit Breakers
D.C. Circuit Breaker
Motor-Operated Circuit Breaker & Switch
Knife-Switch
Set of Transformers
All H.T. Circuits Indicated by Single Lines are three-phase
Sw. Sta.—Switching Station



ALARM CIRCUITS
Train & Locomotive Despatcher Room No.241
Interlocking Station "A"
Train Director's Room
Relay
Interlocking Station "C"
Interlocking Station "D"
3-Pin Register
North Tunnel
South Tunnel
Tunnel No.4
Tunnel No.3
Tunnel No.2
Tunnel No.1
650-V. Bus
110-V. Control Bus
Alarm Panel Sub-Sta. No. 3
Alarm Panel Sub-Sta. No.2
STA.
4 A
SW. STA. NO. 3 A
SW. STA. NO. 2 A.
SW. STA. NO. 3 B
SW. STA. NO. 2 B.
PENNSYLVANIA STATION
650-V. D.C. Positive Buses
Rotary
Starting Transformer
High-Tension Buses
No.23
No.7
No.6
No.24
No.5
No.1
No.4
No.3
No.2
SUB-STATION NO. 3
SUB-STATION NO. 2
SUB
LONG
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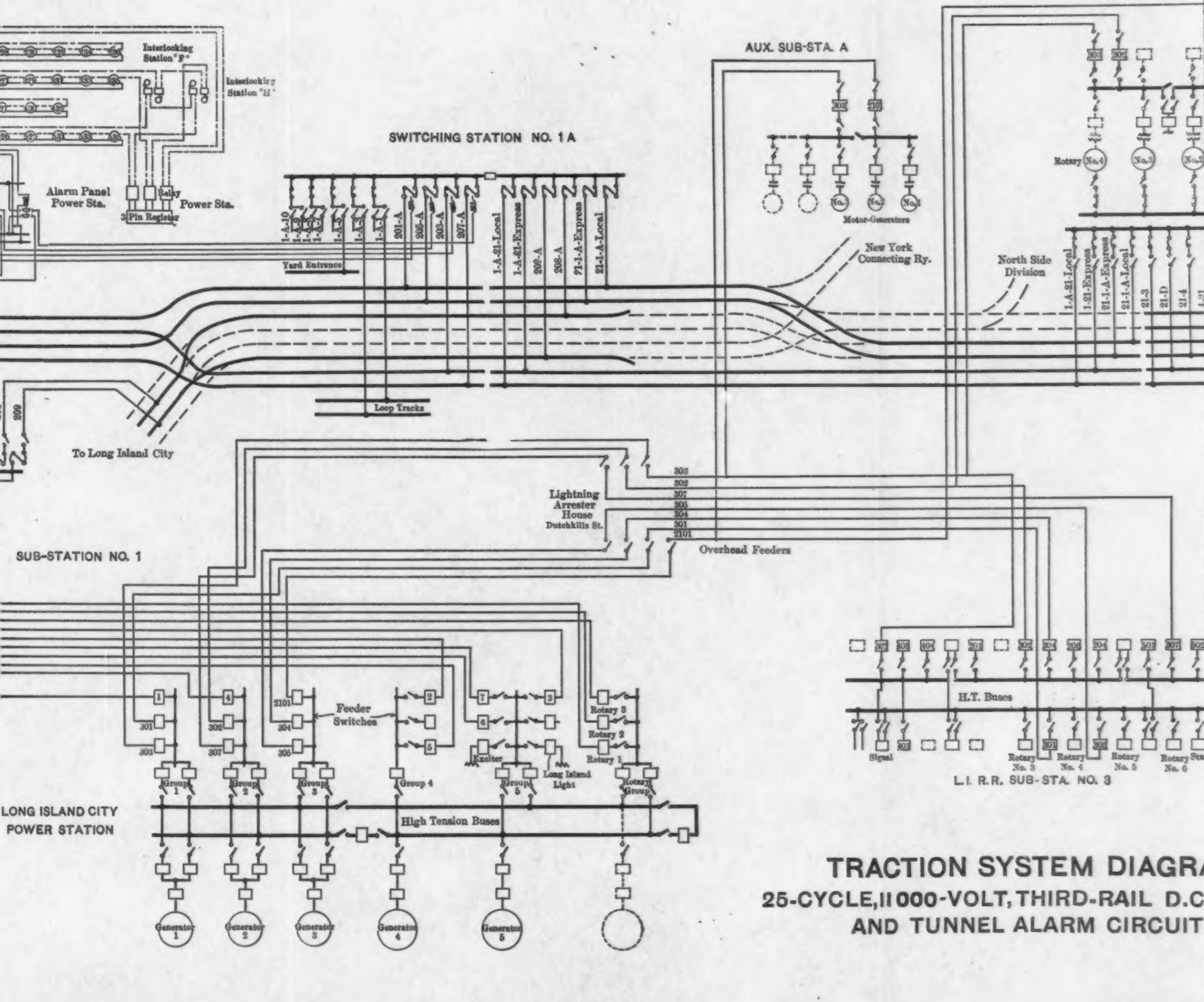
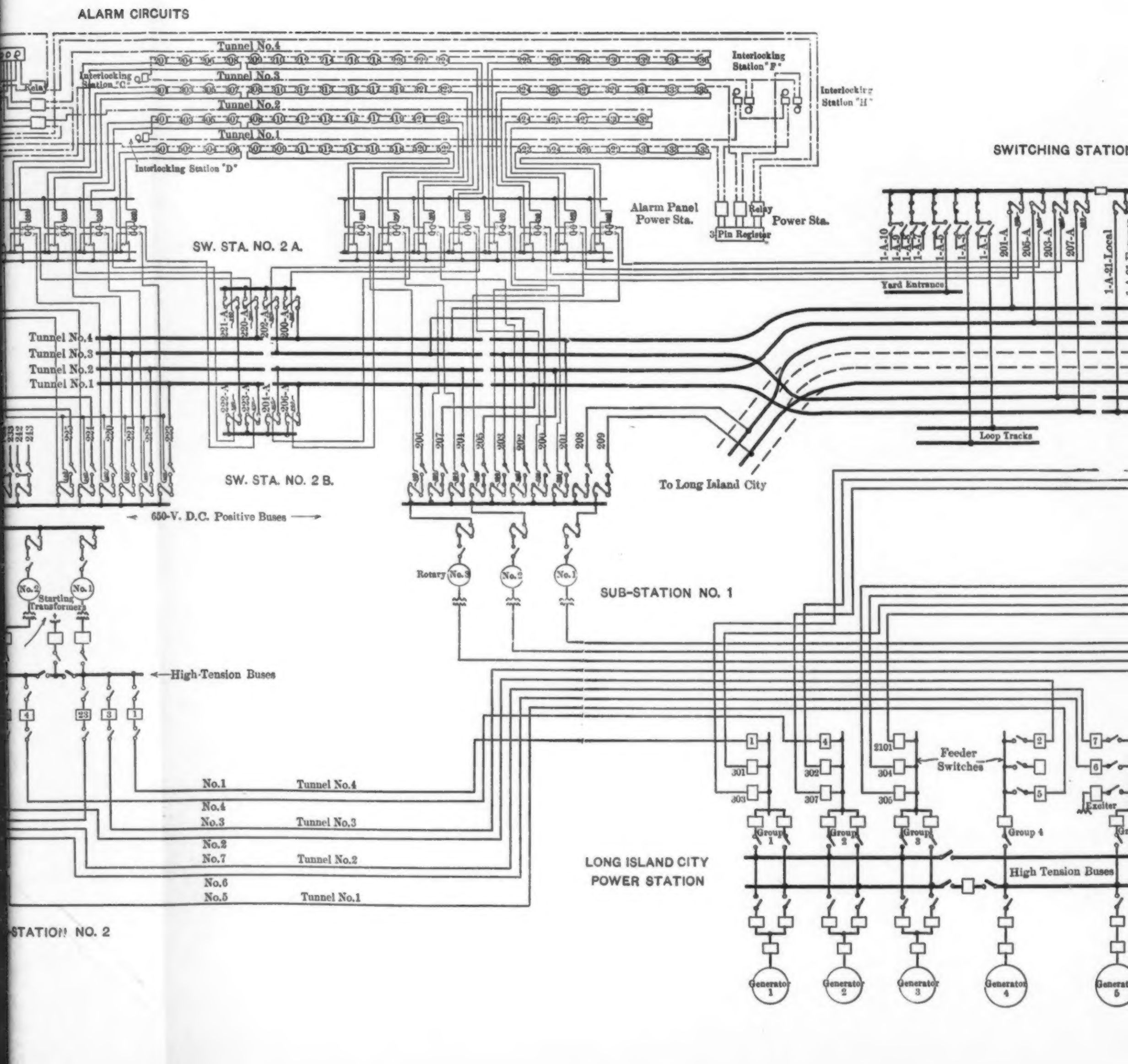
rs

PLATE CV
TRANS. AM. SOC. C
VOL. LXIX, No
GIBBS ON
PENN. R. R. TUNNELS: STATIO



TRACTION SYSTEM DIAGRA

25-CYCLE, 11 000-VOLT, THIRD-RAIL D.C.
AND TUNNEL ALARM CIRCUITS



ALARM CIRCUITS
Tunnel No.4
Tunnel No.3
Tunnel No.2
Tunnel No.1
Relay
Interlocking Station "C"
Interlocking Station "D"
Interlocking Station "F"
Interlocking Station "H"
Alarm Panel Power Sta.
Relay
Power Sta.
3 Pin Register
SWITCHING STATION
SW. STA. NO. 2 A.
SW. STA. NO. 2 B.
Yard Entrance
Loop Tracks
To Long Island City
650-V. D.C. Positive Buses
Rotary No.3
No.2
No.1
SUB-STATION NO. 1
Starting Transformers
High-Tension Buses
No.1 Tunnel No.4
No.4
No.3 Tunnel No.3
No.8
No.7 Tunnel No.2
No.6
No.5 Tunnel No.1
LONG ISLAND CITY POWER STATION
Feeder Switches
Exciter
Group 1
Group 2
Group 3
Group 4
High Tension Buses
Generator 1
Generator 2
Generator 3
Generator 4
Generator 5
-STATION NO. 2

PLATE CVI.
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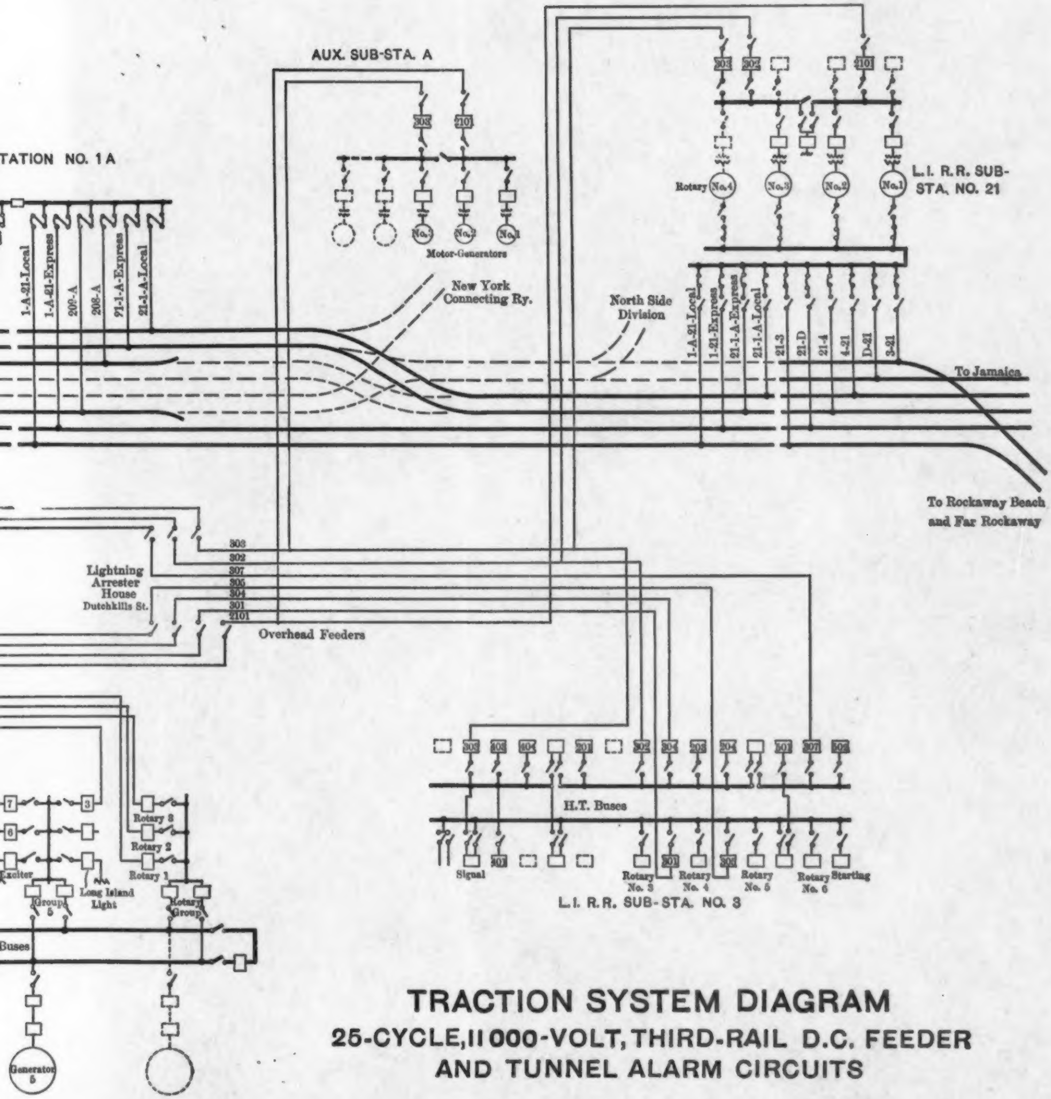
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.



TRACTION SYSTEM DIAGRAM

25-CYCLE, 11 000-VOLT, THIRD-RAIL D.C. FEEDER AND TUNNEL ALARM CIRCUITS

able grid resistance adjusted to limit the flow of current when the line becomes grounded.

The 60-cycle switching apparatus is similar in every way to the 25-cycle equipment, except that a single set of bus-bars is used and is provided with knife-switches for dividing the two sections in emergencies.

The machinery equipment of this power-house, excluding the traction sub-station (given elsewhere), may be concisely listed as follows:

Coal pocket at top of building; capacity, 5 200 tons.
Thirty-two 564-h.p. water-tube boilers, 200 lb. working pressure, 125° superheat. Space for 16 additional 564-h.p. boilers.
Boilers equipped with 32 Type D, Roney stokers, 150 in. wide, 12 grates deep.
Two 8 000-kw., 11 000-volt, 3-phase, 25-cycle, turbo-generators, and space for one additional, for traction power.
Three 5 500-kw., 11 000-volt, 3-phase, 25-cycle, turbo-generators, for traction power.
Two 3 000-kw., 11 000-volt, 3-phase, 60-cycle, turbo-generators, for auxiliary power.
One 200-kw., motor-driven exciter.
One 50-kw., motor-driven exciter.
Two 200-kw., turbine-driven exciters.
One 360-ampere-hour, storage battery of 110 cells.
One Tirrill regulator for 25-cycle generators.
One Tirrill regulator for 60-cycle generators.
Three 175-kw., oil-cooled transformers.
Thirteen 1 200-ampere, 11 000-volt, Type C, oil circuit-breakers.
Thirty-nine 600-ampere, 11 000-volt, Type C, oil circuit-breakers.

Switch-board:

One bench-board, eight panels, for control of 25-cycle generators; and three panels for control of 60-cycle generators.
Six 25-cycle, generator panels.
Two 60-cycle, generator panels.
Two 25-cycle, station panels.
One 60-cycle, station panel.

Transmission.

The transmission of electrical energy from the power-house is entirely 11 000-volt, three-phase, alternating current, the traction power being 25-cycle and the auxiliary power 60-cycle (see Plate CVI). The distribution of all power is by three-conductor, paper-insulated, lead-

covered cables, drawn into the conduits between the switch-boards and the shafts communicating to the tunnels.

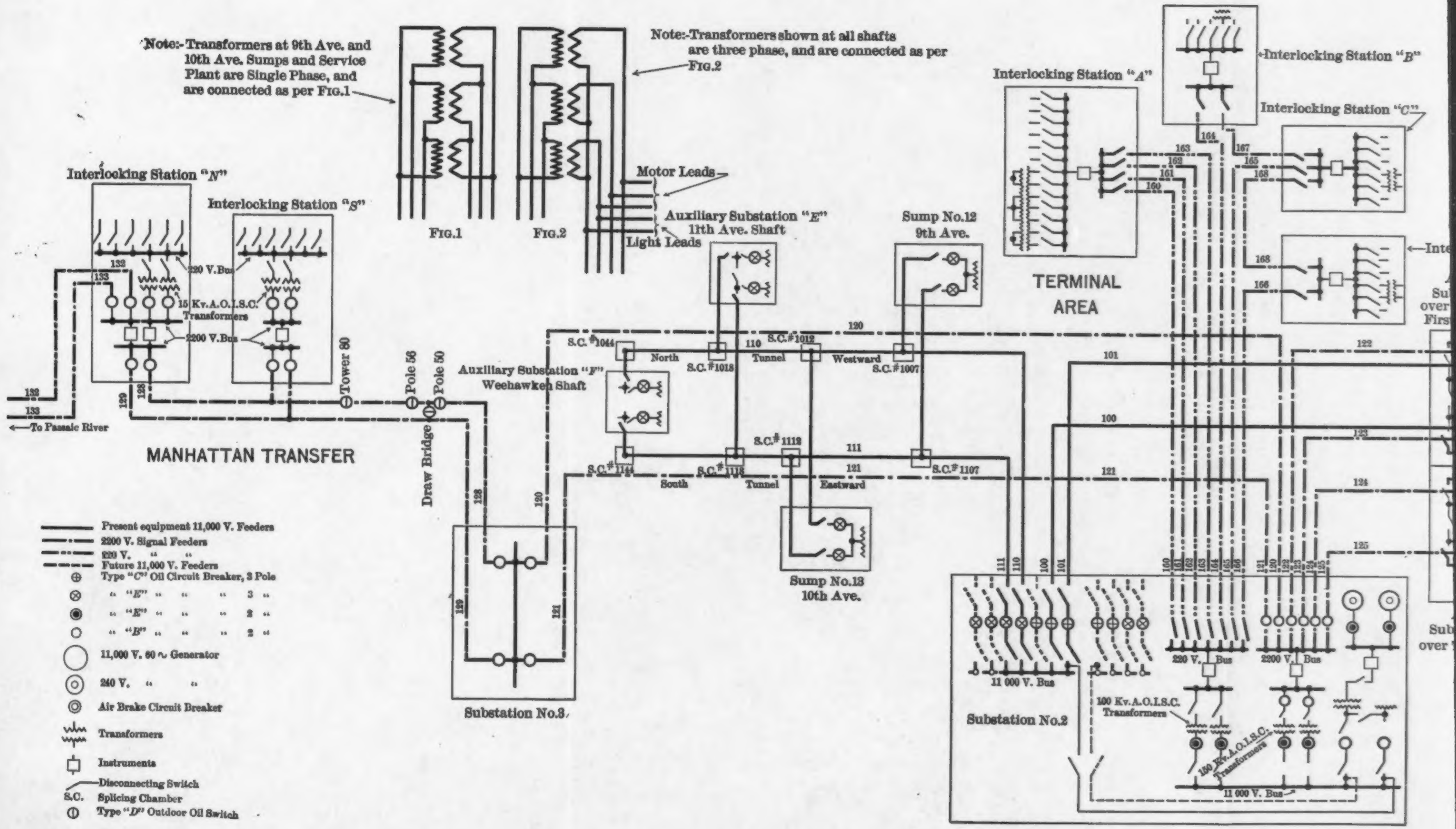
Four power cables run from the Power-House direct to Service Plant Sub-station No. 2; three additional power cables run direct from the Power-House to Sub-station No. 3, at Hackensack Portal, New Jersey; and two extension cables connect Sub-stations Nos. 2 and 3. At Sub-station No. 3 these feeders leave the house in three 3-phase open-wire circuits on the steel pole line, crossing the Meadows and terminating at Sub-station No. 4, at Harrison. All these 25-cycle feeders are of 250 000 cir. mils section per conductor.

Power for the Long Island Railroad is supplied in a similar manner through seven high-tension cables laid in the conduit system to an arrester-house at the west end of Sunnyside Yard, from which open circuits are continued, through suitable lightning arresters, overhead on a steel pole line through the yard, and thence to various sub-stations on the Long Island electric traction system.

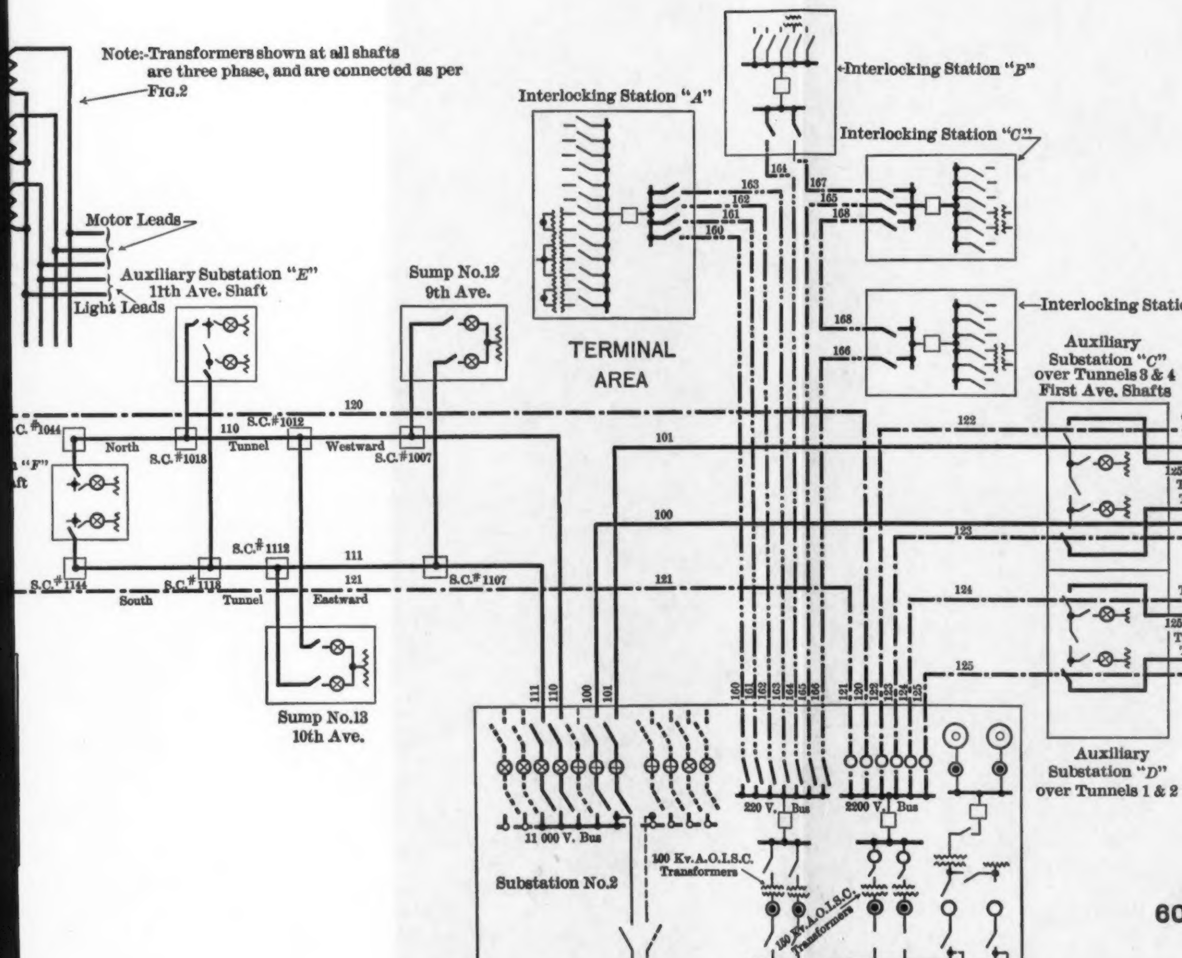
As before mentioned, the potential of the high-tension lines is from 11 000 to 12 000 volts, this being sufficiently high for economical transmission for the distance at which power is at present used on the Pennsylvania and the Long Island systems; it is a suitable potential for direct generation without using step-up transformers, and is a commercial voltage for insulated cable. To provide for the contingency of an extension of the traction system on the New Jersey side beyond Newark, or for tie lines to a future power-house, space has been provided on the pole line for additional circuits suitably spaced for 33 000-volt transmission. In the event of such requirement, it is intended to provide step-up transformers in the Hackensack Portal Sub-station, and a 33 000-volt line westward therefrom.

Auxiliary power (60 cycles) is transmitted from the power-house through the tunnels to the Service Plant in a similar way (see Plate CVII), by four cables, two of these going to the Service Plant direct, and two to the tunnel shaft-houses for tunnel lighting and miscellaneous power. The two cables to the Service Plant have conductors of No. 00 B. & S. section, and those to the tunnel shaft houses have conductors of No. 4 B. & S. section.

As there are four tunnels under the East River, the 25-cycle and 60-cycle cables are subdivided into groups and distributed through the tunnels so that there is a duplication of routes, as well as cables, for



Note:- Transformers at 9th Ave. and 10th Ave. Sumps and Service Plant are Single Phase, and are connected as per Fig.1
Note:-Transformers shown at all shafts are three phase, and are connected as per Fig.2
Fig.1
Fig.2
Motor Leads
Light Leads
Auxiliary Substation "E" 11th Ave. Shaft
Sump No.12 9th Ave.
Sump No.13 10th Ave.
Interlocking Station "A"
Interlocking Station "B"
Interlocking Station "C"
TERMINAL AREA
Interlocking Station "N"
Interlocking Station "S"
220 V. Bus
15 Kv.A.O.I.S.C. Transformers
2200 V. Bus
To Passaic River
MANHATTAN TRANSFER
Tower 80
Pole 56
Pole 50
Draw Bridge
Auxiliary Substation "F" Weehawken Shaft
S.C. #1044
S.C. #1018
S.C. #1012
S.C. #1007
S.C. #1144
S.C. #1118
S.C. #1112
S.C. #1107
North
Tunnel
Westward
South
Tunnel
Eastward
Substation No.3
Substation No.2
11 000 V. Bus
220 V. Bus
2200 V. Bus
100 Kv.A.O.I.S.C. Transformers
150 Kv.A.O.I.S.C. Transformers
Present equipment 11,000 V. Feeders
2200 V. Signal Feeders
220 V. " "
Future 11,000 V. Feeders
Type "C" Oil Circuit Breaker, 3 Pole
" "E" " " " 3 "
" "E" " " " 2 "
" "B" " " " 2 "
11,000 V. 60 ~ Generator
240 V. " "
Air Brake Circuit Breaker
Transformers
Instruments
Disconnecting Switch
S.C. Splicing Chamber
Type "D" Outdoor Oil Switch



Note:-Transformers shown at all shafts are three phase, and are connected as per FIG.2
Motor Leads
Auxiliary Substation "E" 11th Ave. Shaft
Light Leads
Sump No.12 9th Ave.
Interlocking Station "A"
Interlocking Station "B"
Interlocking Station "C"
TERMINAL AREA
Auxiliary Substation "C" over Tunnels 3 & 4 First Ave. Shafts
North
Tunnel
Westward
South
Tunnel
Eastward
S.C.#1044
S.C.#1018
S.C.#1012
S.C.#1007
S.C.#1144
S.C.#1118
S.C.#1112
S.C.#1107
Sump No.13 10th Ave.
Auxiliary Substation "D" over Tunnels 1 & 2
11 000 V. Bus
220 V. Bus
2200 V. Bus
100 Kv.A.O.I.S.C. Transformers
150 Kv.A.O.I.S.C. Transformers
Substation No.2
11 000 V. Bus

PLATE CVII.
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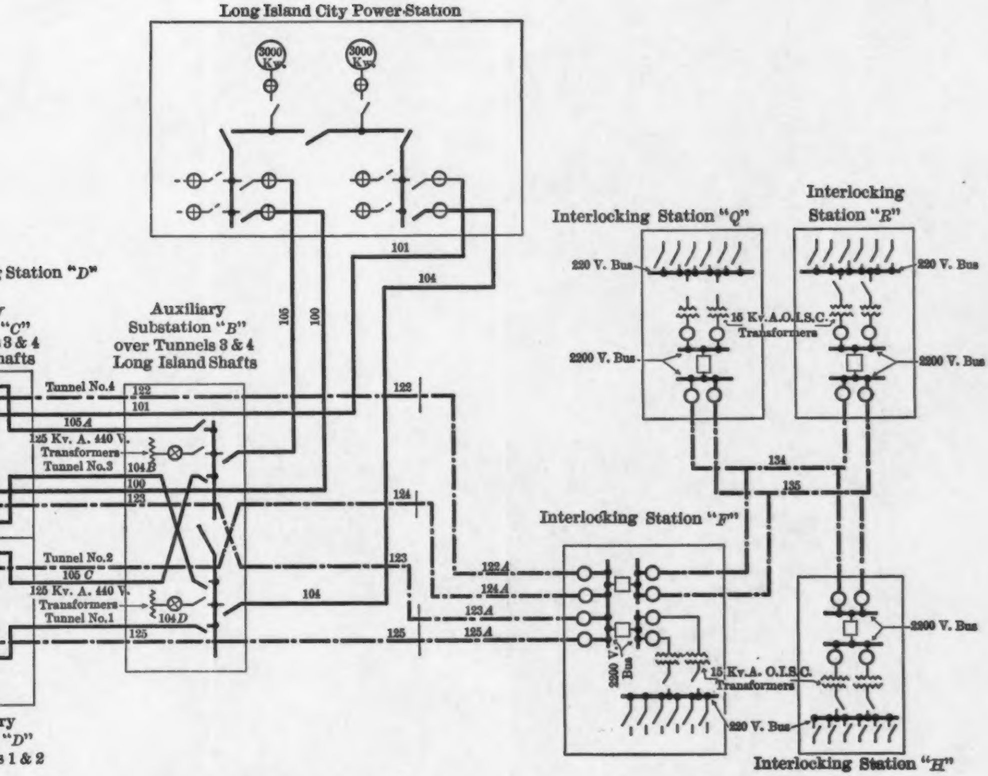

DIAGRAM OF AUXILIARY POWER SYSTEM 60-CYCLE, 11000-VOLT, HIGH-TENSION AND SIGNAL FEEDERS

all services. Between the power-house and the shafts the conduit lines are divided into two groups with separate manholes, in each of which approximately half of the cables of each type are run. Similarly, the cables for the Long Island transmission are kept entirely distinct from those of the tunnel operation.

Furthermore, in providing cables for various purposes, by the above arrangement each sub-station has three or more traction power cables, two of which are ample to carry the load, and the auxiliary power cables are in duplicate; thus there is a margin of from 30 to 50% in the capacity of the cables, to provide against break-down.

Each cable is provided at each end with a high-tension, automatic, oil circuit-breaker, disconnecting switches, and section bus-bars, so as to give complete control of the cables when in operation and permit of the isolation of one or more cables or sections of the bus-bars for repair purposes without interfering with the operation of the remaining cables and sections.

At splicing chambers in the duct system, and where the cables are exposed in the sub-stations, the lead sheathings of the cables are connected and grounded at intervals for protection against electrolysis.

Traction Sub-stations.

There are four traction sub-stations for the Terminal Division, and their locations have been fixed with reference to the loading requirements and by certain physical conditions along the line.

No. 1 has been placed in the Power-House, and supplies the East River tunnel lines, Sunnyside Yard, and the Long Island tracks through the yard to a point where the load is taken by the first sub-station of the latter road. This location secures economy in first cost and operation of the direct-current supply for this section. No. 2, in the Service Plant, adjoins the main yard, and is centrally located for movements in the yard, the East River and North River Tunnels. No. 3 is at the Hackensack Portals, because of the desirability of having the power supply near the tunnel grades, and in order to permit of changing from underground cables to overhead line construction at the first point where such a change was permissible; it obviates separate provisions for housing switching apparatus and for lightning protection at a point between sub-stations. No. 4 is at the junction of the Terminal and the New York Divisions, making it available for

supplying power, not only to the Terminal Division, but for the Rapid Transit line between Newark and Jersey City, in connection with the Hudson and Manhattan Company's tunnels to Church Street, Manhattan. Plate CVIII shows the interior of this sub-station.

TABLE 9.—SUB-STATIONS.

Sub-Station.	No. 1.	No. 2.	No. 3.	No. 4.
Location	Long Island City Power-house.	Service Plant.	Hackensack Portal.	Harrison.
Incoming high-tension feeders	3	4	5	3
Outgoing high-tension feeders	....	2	3	....
High-tension lightning arresters	....	....	3	3
Size of rotaries	2 000-kw., 6-Ph.	2 000-kw., 6-Ph.	2 000-kw., 6-Ph.	2 000-kw., 6-Ph.
Number of rotaries	3	3	3	3
D. C. voltage	650	650	650	650
Main transformers	750-kw., air-blast.	750-kw., air-blast.	750-kw., air-blast.	750-kw., air-blast.
No. of transformers	9	9	9	9
Starting transformers	125-kw., O. I. S. C.	75-kw., O. I. S. C.	75-kw., O. I. S. C.	75-kw., O. I. S. C.
No. start. transformers	3	3	3	3
No. H. T. panels	0	4	8	3
No. rotary panels	4	4	4	4
No. aux. power panels	....	....	2	2
No. D. C. feeder panels	11	19	6	9
No. load panels	1	1	1	1
No. blowers	2-20 000 cu. ft.	2-20 000 cu. ft.	2-20 000 cu. ft.	2-20 000 cu. ft.
No. motor-generating sets	....	....	1	1
Size control battery	....	....	20-amp., 55-cell	20-amp., 55-cell.

Equipment.—In each of the sub-stations there are installed high-tension switching apparatus, step-down transformers of the air-blast type, and three 2 000-kw. rotary converters for converting the alternating into direct current for traction purposes, also, the necessary low-tension switching apparatus for controlling the outgoing direct current to the various third-rail feeders. The normal direct-current voltage is 650, and the machines are designed with special reference to the fluctuating nature of the traction load, and will operate up to 200% overload. Two of the rotaries in each sub-station will carry the load on that sub-station, the third being in reserve, and space is provided in the buildings for an additional machine when required.

The apparatus has been arranged with special reference to economy in the number of attendants required in the operation, the machinery and switch-boards being on the same floor. In all sub-stations the high-tension circuit-breakers are remote-controlled electrically from the switch-boards, and in Nos. 1 and 2 the direct-current switches and breakers are operated by small motors and are remote-controlled.

PLATE CVIII.

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GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.

TRACTION SUB-STATION AT HARRISON.

Auxiliary Power Sub-stations.

There are six sub-stations at convenient points for supplying the tunnels and yards with auxiliary power for the various purposes described elsewhere; they have been designated by letters in order to distinguish them from the traction sub-stations.

Auxiliary Sub-station "A."—Sub-station "A" is in Sunnyside Yard, and is the only one using 25-cycle current. The 11 000-volt, 3-phase, 25-cycle power is obtained from two of the overhead Long Island Railroad feeders passing the yard; it is stepped down in suitable transformers, and converted by three 250-kw. motor-generators into 110 to 220-volt, 3-wire, direct-current power for charging train batteries, yard and building lighting, operation of elevators, and for miscellaneous motors for driving machine tools, cranes, refrigerating plant, etc.

TABLE 10.—AUXILIARY POWER SUB-STATIONS.

Designation.	"A"	"B."	"C."	"D."	"E."	"F."
Location	Sunnyside Yard.	L. I. Shaft House, 3 and 4.	1st Ave. Shaft House, 3 and 4.	1st Ave. Shaft House, 1 and 2.	11th Ave. Shaft.	Weehawken Shaft.
11 000-volt feeders	Two 25-cycle.	Two 60-cycle.	Two 60-cycle.	Two 60-cycle.	Two 60-cycle.	Two 60-cycle.
Transformers	Nine 125-kw.	Two 125-kw.	One 125-kw. One 75-kw.	One 125-kw. One 75-kw.	Two 75-kw.	Two 75-kw.
Motor generators	Three 250-kw.	....	....	....	....	....
Horse power of motors supplied	250	206.5	105	110	87.5	140
Switch-board panels	34	4	2	2	2	2
Arc lamps supplied	50	....	....	....	....	....
Approximate number of incandescent lamps	1 100	1 100	625	625	300	800
Battery charging outlets	450	....	....	....	....	....
Voltage of motors	220	440	440	440	440	440
Voltage of lamps	110	32	32	32	32	32

The car-battery charging switch-board in this plant is worthy of special mention. The placing of cars at fixed positions required that their lighting batteries should be charged at any point in the yard, covering thirty-four tracks, with a total trackage length of 7 miles. In order to reach any car, it was necessary to provide circuits from a central point to outlets approximately 70 ft. apart at each track, and to make provision in the sub-station for a controlling switch-board of 34 panels. On these are mounted 476 five-point switches, which connect through suitable resistances to the respective outlets at the

tracks for regulating the current supplied to each battery. On these panels means are also provided for indicating the charging current and voltage on each circuit. The board was specially designed to occupy the minimum space, the 34 panels requiring a length of only 68 ft.

Auxiliary Sub-station "B."—Sub-station "B" is in the house over the shafts of Tunnels Nos. 3 and 4, at Long Island City. It is connected with the Power-House by two feeders. Step-down transformers are installed to supply power at 440 volts, 3-phase, to operate motors at the shaft sumps and at the Sunnyside Yard portals of the tunnels; also motors for operating the ventilating fans at this point. The same transformers, by a connection to the neutral point, supply 252-volt, single-phase current for lighting the tunnels. From this sub-station one 3-phase, 11 000-volt cable is run through each of the four tunnels to Auxiliary Sub-stations "C" and "D"; two to each sub-station.

Auxiliary Sub-stations "C" and "D."—Sub-station "C" is over the First Avenue shaft of Tunnels Nos. 3 and 4, and "D" is over the shaft of Tunnels Nos. 1 and 2. Two sub-stations were provided at this point because it was not feasible to connect the two shaft-houses by ducts and power cables, as was done at Long Island City. These sub-stations are similar to "B," except that there are no outgoing 11 000-volt cables. In each of these sub-stations is installed a step-down transformer for supplying alternating-current power to the fan and pump motors and for the tunnel lights.

Auxiliary Sub-stations "E" and "F."—Sub-stations "E" and "F" are at the Eleventh Avenue and Weehawken shafts, respectively, of the North River Section, and are supplied with 11 000-volt current by two cables from the Service Plant. These cables are tapped into Sub-station "E" at the Eleventh Avenue shaft, and terminate at Sub-station "F." Each sub-station is equipped with lowering transformers for operating motors for sump pumping, ventilating, and tunnel lighting.

Switching Stations.

Intermediate between the traction sub-stations are located switching stations, in chambers built in the tunnel system, and in small buildings adjacent to the line in the open. These stations are not provided with attendants; they contain switches for sectionalizing and cross-connecting the direct-current third-rail system. With two exceptions, the stations are equipped for the remote control of switches and circuit-

breakers, and are operated from the nearest traction sub-station by special control circuits; the two which are provided with hand-controlled switches are at or near signal cabins, and are operated by the signalman.

TABLE 11.—SWITCHING STATIONS (THIRD-RAIL SYSTEM).

No.	Location.	No. of main line feeders.	No. of yard feeders.	4 000-AMPERE CIRCUIT-BREAKERS: Hand-operated.	4 000-AMPERE CIRCUIT-BREAKERS: Remote-controlled.
1-A	Sunnyside Yard	10	7	6	10
2-A	Tunnel No. 3 west of First Avenue Shaft	4	..	..	4
2-B.	Tunnel No. 2 west of First Avenue Shaft	4	..	..	4
3-A	East of Weehawken Shaft	4	..	..	4
3-B	Secaucus	3	..	..	2
4-A	Hackensack River	5	..	5	..
4-B.	Signal Cabin "N", Manhattan Transfer	4	1	5	..

Distribution and Control.

Distributing Circuits.—In general, the direct-current traction feeder circuits consist only of the third-rail and track return, with short cable connections between the sub-stations and the third-rails and tracks, these being sufficient to carry the currents without excessive losses. The only exception is between Sub-stations Nos. 3 and 4, where the distance is such that it is necessary to supplement the third-rail and track return by a positive and negative feeder; these are each of 2 000 000 cir. mils section, and are carried on the high-tension pole line. The return feeder is continuous between sub-stations, with a connection to each track at each automatic signal. The positive feeder is omitted between switching stations.

It is necessary, in order to avoid undue current loss or excessive first cost, to connect all sub-stations in parallel through the third-rail, and to interconnect the third-rails of the two tracks at intermediate points between sub-stations. An accident, such as the grounding of the third-rail, under these conditions, however, would ordinarily affect the entire section of line; in order, therefore, to secure the advantages of the interconnected system, and at the same time to permit of ready isolation of any section of track without interfering with operation on the adjacent tracks, a system of sectionalizing was installed. To do this, the switching stations above referred to have been provided, in

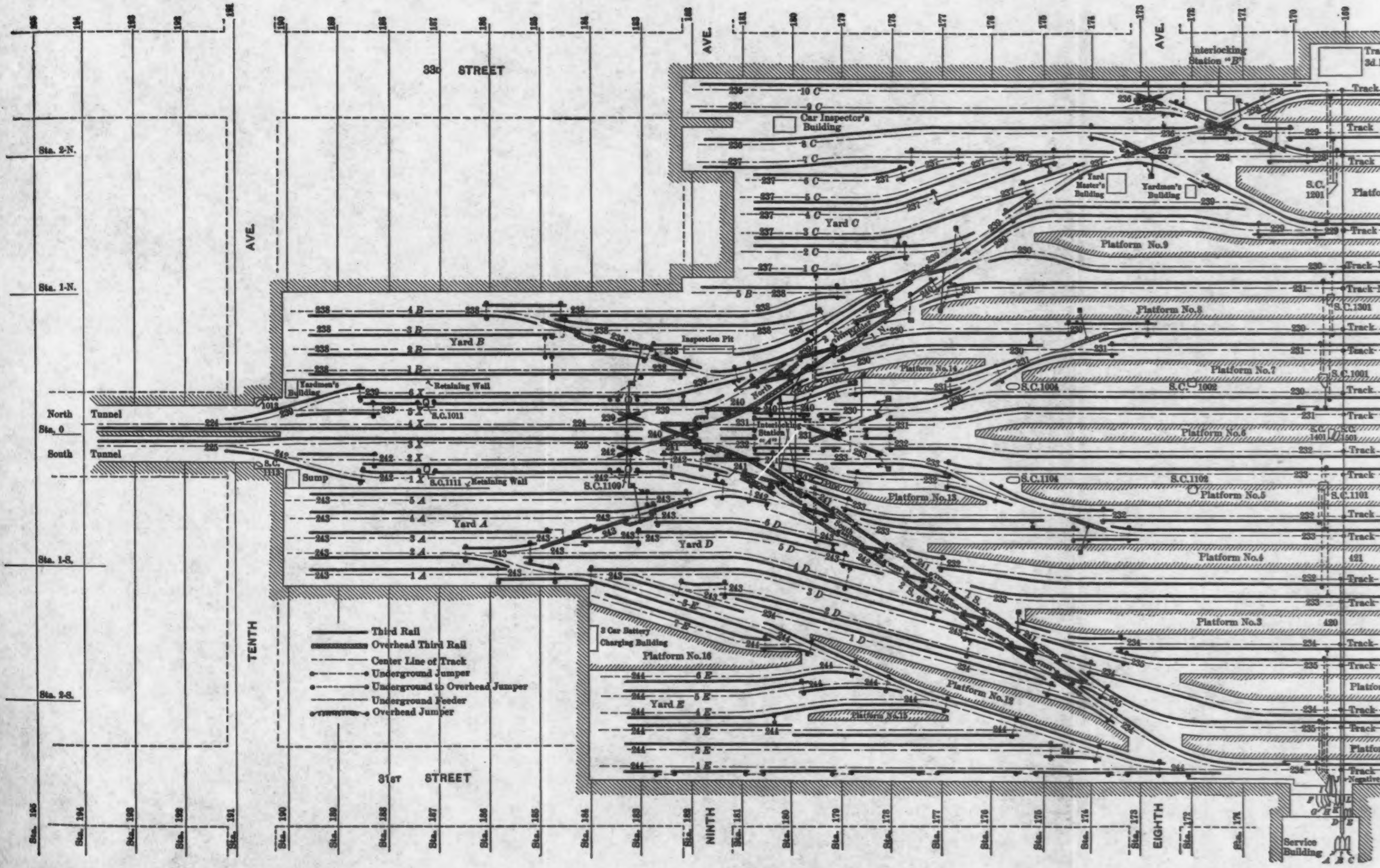
addition to the normal switching apparatus in the sub-stations; and the connections at the switching stations are such that by remote control the operator in any sub-station has complete control of each section of track between that sub-station and the nearest switching station. The circuit-breakers are also automatic at both points, so that on over-load or short-circuit the section affected is cut out only between the sub-station and the nearest switching station, and on one track only.

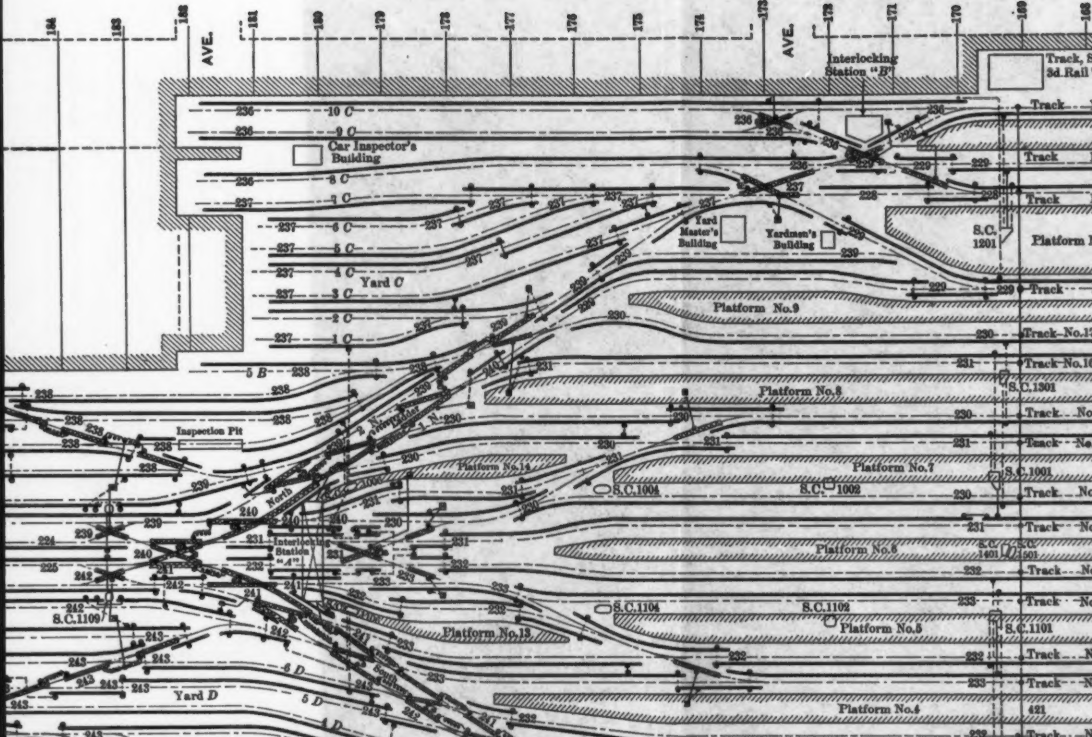
To restore the section after the over-load, the operator closes a switch in the sub-station, and this, through the remote-control circuit, actuates the switch in the switching station. At the hand-operated switching stations, the switches are closed by the signalmen on receiving instructions from the sub-stations.

At the yards a complete system of sectioning is also provided. This is especially necessary because of the multiplicity of tracks, and the necessity for isolating a limited section only, which may be affected by the accident. In the station yard the tracks are divided into twenty-one sections, as shown on Plate CIX, and these are planned so that an accident on any one section will not interfere with through movements on the main tracks, and will not isolate an undue portion of the station tracks. The station yard sectioning is effected by switches in the Service Plant Sub-station, and is under the control of the operator there. Similarly, the third-rails of the Sunnyside Yard tracks are divided into seven sections, controlled in the yard switching station.

Third-Rail Sectioning Switches.—In addition to the provisions for sectioning and cross-connecting the third-rails, as above described, this rail in each tunnel is sub-divided into sections, each about 1 500 ft. in length, by quick-break knife-switches. These are located approximately at each of the signals, and where the signals are far apart they are placed half way between. They are normally closed, but may be opened in emergencies, such as wreck or derailment, or the grounding of the third-rail, so as to localize the trouble and allow trains not immediately within this section to be operated out of the tunnel, and also to allow electric wrecking trains to be operated close to the point of derailment to assist in clearing up the wreck, or to haul stalled equipment from the tunnels.

"Power Off" Signals.—In connection with the sub-division of the third-rail into sections controlled from sub-stations and switching sta-


33d STREET
31st STREET
TENTH AVE.
NINTH AVE.
EIGHTH AVE.
Sta. 2-N.
Sta. 1-N.
Sta. 0
Sta. 1-S.
Sta. 2-S.
North Tunnel
South Tunnel
Yardmen's Building
Sump
Retaining Wall
Car Inspector's Building
Interlocking Station "B"
Yard Master's Building
Yardmen's Building
Inspection Pit
Interlocking Station "A"
Yard A
Yard B
Yard C
Yard D
Yard E
Platform No.3
Platform No.4
Platform No.5
Platform No.6
Platform No.7
Platform No.8
Platform No.9
Platform No.12
Platform No.13
Platform No.14
Platform No.15
Platform No.16
S.C.1002
S.C.1004
S.C.1011
S.C.1100
S.C.1101
S.C.1102
S.C.1104
S.C.1111
S.C.1201
S.C.1301
3 Car Battery Charging Building
Service Building
Negative Feeder
Third Rail
Overhead Third Rail
Center Line of Track
Underground Jumper
Underground to Overhead Jumper
Underground Feeder
Overhead Jumper



AVE.
NINTH
EIGHTH
Interlocking Station "B"
Track, S 3d Rail
Car Inspector's Building
Yard Master's Building
Yardmen's Building
Yard C
Yard D
Yard E
Inspection Pit
Interlocking Station "A"
Platform No.3
Platform No.4
Platform No.5
Platform No.6
Platform No.7
Platform No.8
Platform No.9
Platform No.12
Platform No.13
Platform No.14
Platform No.15
Platform No.16
3 Car Battery Charging Building
Service Building
S.C. 1201
S.C.1301
S.C.1001
S.C.1004
S.C.1002
S.C. 1401
S.C. 501
S.C.1104
S.C.1102
S.C.1101
S.C.1109
Negative Feed

PLATE CIX.
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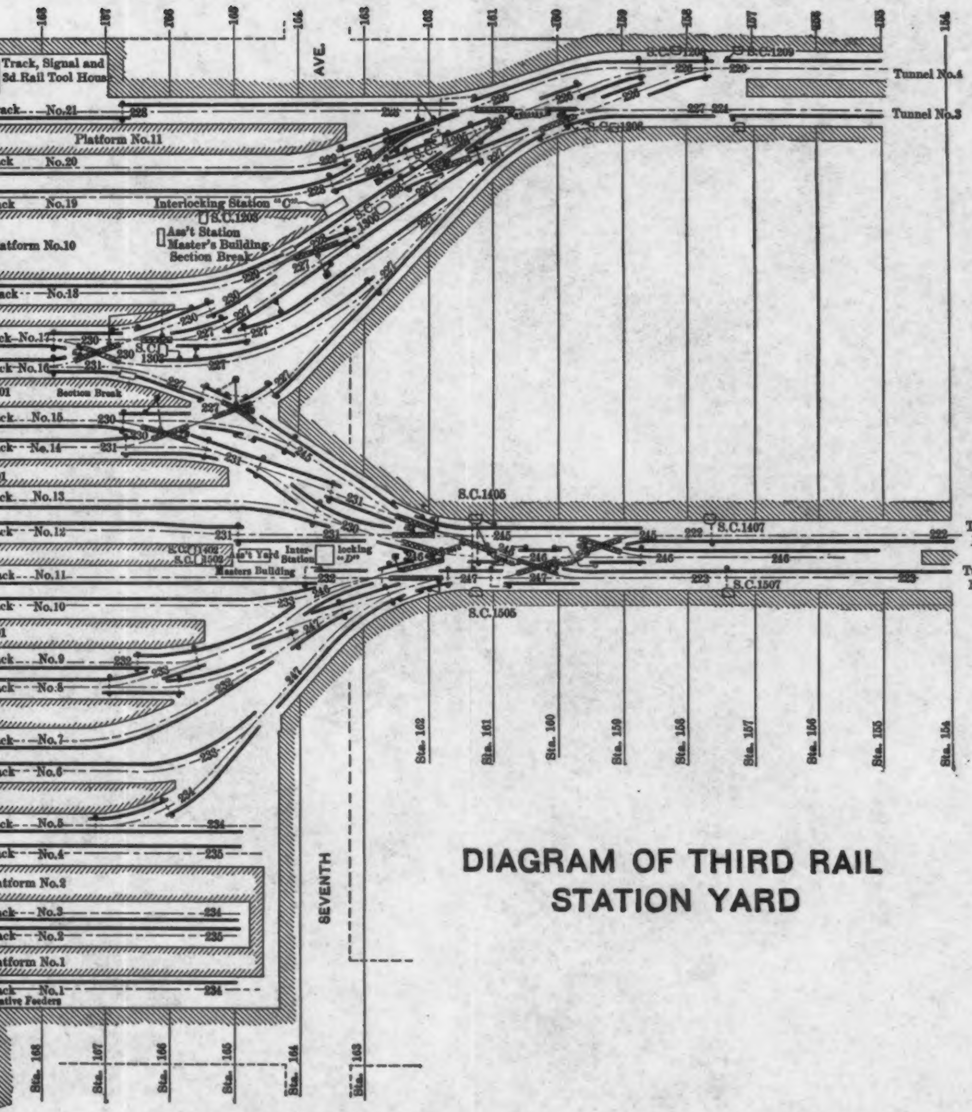


DIAGRAM OF THIRD RAIL STATION YARD

tions, provisions have been made to prevent a train from running on a dead section of third-rail. To do this, the rail is sectioned at certain of the automatic signals, and a relay is provided, with connections to the third-rail and to the signal, to which the circuits are arranged so that when the rail is dead the signal indication will be "Stop," and at the same time a gong will ring at the signal to notify the motorman, when he brings his train to a stop, that he is not to proceed. Where the sections occur at interlockings, the indication is given to the operator in the signal cabin.

Tunnel Alarm System.—Certain conditions may occur when it may be desirable to cut off the current from the third-rail because of a high-resistance ground or a short-circuit which does not pass sufficient current to actuate the automatic circuit-breakers in the sub-stations and switching stations, or when there may be danger of injury to workmen or others by accidental contact with the third-rail. In such emergencies the tunnel alarm system permits of immediately making the third-rail dead. The details of this system are described in the section devoted to "Tunnels."

Third-Rail and Track Return.

The Terminal operation, as elsewhere explained, required through service with the existing traction system of the Long Island Railroad, comprising more than 100 miles of electrified track. The top-contact type of third-rail is in use on this latter road, and has been found satisfactory, the cost of maintenance being very low, and it has the important advantage of simplicity of parts, flexibility, ease of maintenance and installation, and is easily repaired in cases of derailment. Third-rail location and clearances have been standardized by the American Railway Association, and, as a matter of course, the Long Island and the Terminal Railroad installations have been made to conform therewith.

Rail Section.—On account of the very heavy currents used for individual trains, and the density of traffic, it is necessary to have large current-carrying capacity and conductivity in the collector system. The capacity is in part fixed by the distance between the feeding points, and the required conductivity may be provided either by a light third-rail, supplemented by copper feeders, or a rail of large cross-section and special composition, which in most cases would require no supplemental feeders. The latter arrangement was adopted as being more economical

in first cost and of greater simplicity. The rail section used on the main-line tracks is the heaviest yet adopted for traction purposes, being 150 lb. per yd., and of special chemical composition, low in carbon and other hardeners, giving a resistance of about eight times that of copper, instead of about twelve times, as in the ordinary track rail.

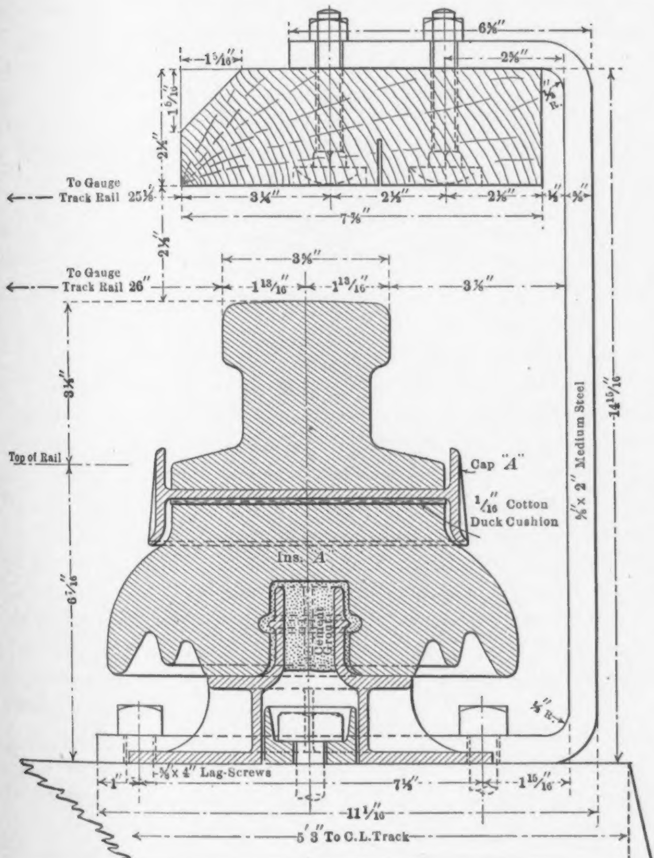
The rail, Fig. 16, is a T section having a vertical height of 4 in. and a lower flange width of 6 in., making a section which allows for ample insulation from the track ties, and is stable against overturning; it also provides for a simple form of splice, and convenient bonding at the joints. In the yards, where the large section is not needed for conductivity, and where it is desirable to have the maximum of clearance for signal and other apparatus along the track, the section consists of 25-lb. standard Bessemer T-rails, Fig. 17, mounted in an inverted position, the foot of the rail constituting the contact surface.

Insulators.—Experience on the Long Island Railroad and elsewhere, with various types of insulators, has resulted in the adoption, by the Terminal Railroad, of a simple and substantial form of insulating block for supporting the third-rail. These blocks are of porcelain, made by the "dry" process, which gives a very tough and mechanically strong insulator, with ample and permanent insulating qualities. For the open sections of the road a simple rectangular block with rounded corners is used; in the tunnels, where in places there is dampness due to condensation, or salt seepage-water, a petticoat-type insulator is used, which furnishes a more extended surface to provide against leakage of current.

Bonding.—The heavy-section rail is bonded with ribbon-type, compressed, terminal foot-bonds, four to a joint, having a conductivity equivalent to 80% of that of the third-rail. The light-section rails for the yards are bonded with the protected-type, pin-terminal cable-bonds.

Protection.—The third-rails throughout are protected by a continuous plank carried on wrought-iron brackets secured to the third-rail ties, as shown by Figs. 16 and 17. On the open line, this plank is of yellow pine, but, in the tunnel, jarrah wood, imported from Australia, has been used, because of its slow-burning qualities.

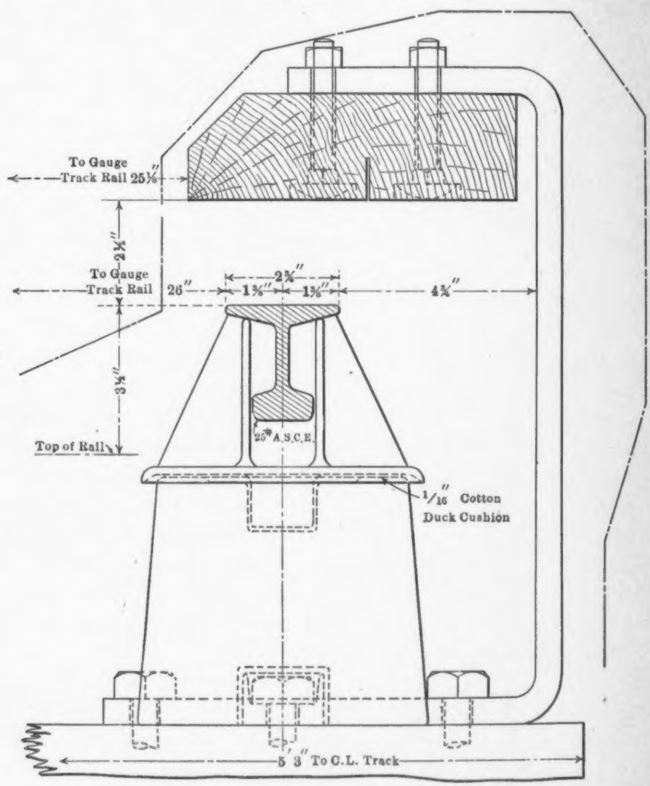
Connections.—The connections to the third-rail from sub- and switching stations are made by insulated cables of 2 000 000 cir. mils section for the heavy rail, and 1 000 000 cir. mils for the light rail. The cables terminate in special porcelain "pot-heads" from which flexible cables are connected to the third-rail by bond terminals.



SECTION OF THIRD RAIL AND PROTECTION
FOR USE IN TUNNELS.

FIG. 16.

Track Bonds.—Throughout the main tracks, both rails of each track are bonded; in the yards, however, as elsewhere explained, only one rail is bonded. In the open, where there is danger of theft of copper, the bonds are of the protected type, placed under the joint angle-bars; in



SECTION OF THIRD RAIL AND PROTECTION FOR YARD TRACKS.

FIG. 17.

the tunnels and terminal yard, from which the public is excluded, long cable bonds are run around the angle-bars. All bonds are of wire cable, provided with forged copper terminals, and are secured in drilled holes in the rails by steel pins driven through the center of the heads. As a

matter of interest, it will be noted that there was great difficulty in drilling the open-hearth steel rails for these connections; it was found that tools suitable for Bessemer rails would drill only from two to four holes in the open-hearth rails; therefore special steels had to be used for the drill bits.

TABLE 12.—Rail Bonds.

Weight of rail.	Rail.	Type of terminal.	Application.	Bonds, per joint.	Circular mils, over bond.	Length of bond, in inches.
150-lb........	Third......	Compressed...	Exposed.......	4	450 000	5 and 10
100-lb.......	Track......	Pin.............	Protected	2	273 397	20 and 25
100-lb........	"	"	Exposed.......	2	400 000	49 and 53.25
100-lb........	"	"	Protected	2	300 000	25
85-lb	"	"	"	2	300 000	15
25-lb........	Third......	"	"	2	0000 B. & S.	12
25-lb	"	"	Exposed.......	2	00 B. & S.	24.25

Overhead Third-Rail.—In order to provide continuous power supply to electric locomotives passing through certain cross-overs and the ladder tracks of the Station Yard, it was found necessary to supplement the usual ground third-rail construction by sections of overhead contact; the arrangement, furthermore, permits of the simplification of the contact system in the complicated special work of the tracks, reduces the number of cable cross-connections, and allows more space for the installation and care of switch-operating apparatus. In general, it has been designed to give continuous contact through all ladders and for important locomotive switching movements, but, for minor movements and single or two-car multiple-unit operation it has been assumed that coasting over gaps in the ground third-rail will be permissible.

The overhead contact consists of a 25-lb., standard-section, T-rail, hung flange downward through insulators from longitudinal lattice box-girders. Under the buildings and viaducts these girders are supported by the floor structure, and in the open yard they are carried by cross-girders supported by columns between tracks. To reduce the number of columns, the cross-girders are designed in part as simple spans, and in part as cantilevers, and the longitudinal system as cantilever trusses having curved top chords. The structure carries generally two parallel lines of third-rail, one for each of the tracks of the double ladder systems; and in many locations it is used as a support for the interlocking and block signals. Reinforced concrete

fenders have been placed at the approach in either direction about the lower portions of all columns, as a protection against damage from derailment of rolling stock.

The locomotives are equipped with air-operated, overhead, pantagraph shoes, which may be raised by the motorman when desired, to make contact with the rail, and the contact surface of the latter is sheathed with heavy sheet-copper, in order to reduce sparking when heavy currents are thus drawn. Multiple-unit motor cars have not been provided with top contact shoes. No overhead contact system has been found necessary in the Sunnyside or Manhattan Transfer Yards.

The following are general data relating to the Station Yard overhead system:

Total length of contact system	3 930 ft.
Total " " " surface	6 210 "
Number of sections of rail	86
Distance from top of track rail to contact surface	15 ft. 4 in.
Distance from top of track to bottom chord of structure	16 ft. 7 in.
Length of complete cantilever span	122 ft.
Depth of cantilever at supports	6 "
Depth of cantilever at middle	3 "
Width of cantilever	3 "
Number of columns required for entire system.	12

Conduit System.

Throughout the tunnels and terminal area, all cables for power, and telephone and telegraph service, are run in a permanent system of tile conduits, described in detail as to their constructive features in other papers. There are in all approximately 400 duct miles of power conduits and 600 duct miles of telephone and telegraph conduits. The general scheme involved in their planning is as follows:

Power Conduits.—The system of power conduits originates at the Long Island City Power-House, from which two separate banks of tile ducts are run to the four water-front tunnel shafts. At these points vertical pipe conduits are embedded in the shaft linings and connect to the splicing chambers of the ducts in the tunnel benches. The ducts extend in one bench of each tunnel eastward to the portals in Long Island City and westward to the throat of the yard, near Seventh Avenue. From this point they are continued westward below the

yard sub-grade to a point opposite the Service Plant between Seventh and Eighth Avenues; thence southward to the splicing chambers in the basement of this building. The arrangement of ducts is similar through the yard to the North River Tunnels and through them to the Bergen Hill Portal; thence they run along the walls of the approach and into Sub-station No. 3, where the duct lines terminate. The conduit system above described furnishes housing for all classes of high-tension cables, and permits of dividing the cables into groups, so that independent duplicate routes are provided to each power-transforming point.

Telephone and Telegraph Conduits.—A similar system has been provided for other than power purposes, such as telephone and telegraph. In the tunnels these ducts occupy the opposite bench from the power ducts, and in the terminal yard they consist of separate lines. This telephone conduit system was designed for the use of the Railroad Company, but connections have been made at various points to other telephone and telegraph systems, in Long Island City, in Manhattan, and in New Jersey. In Long Island City the conduits terminate at the tunnel portals, but at the water-front certain ducts have been brought to the surface at the First Avenue shaft and others at Sixth Avenue, 32d and 33d Streets. In the terminal yard a number of ducts terminate at a distributing chamber under the Station Building, and others at Ninth Avenue. At the Hackensack Portal all ducts terminate, and connection is here made with the pole lines of the Postal Telegraph Cable Company and the Railroad Company.

It will be noted, from Table 13, that the number of conduits in the various sections is not the same; this was caused by the advisability of installing in the permanent tunnel construction as many ducts as there was convenient space for, the limit being the maximum number of cables which could be cared for properly in the splicing chambers. Obviously, therefore, there are fewer ducts in the river tunnels, where the size of the splicing chambers is limited, than in the land tunnels and the Station area.

Pole Lines.

The Meadows section of the railroad is a 5-mile continuous stretch of semi-tidal meadow swamp land, except for a short section of rock outcropping at Snake Hill. The Hackensack River is crossed midway of the section. The ground surface is covered with a heavy growth

of reeds, and the top stratum is a peaty bog, from 8 to 15 ft. deep, underlaid with varying strata of clay, fine sand, and mixed sand and clay for very considerable depths. Across this section, and adjoining the track embankment, a pole line was erected for telegraph and telephone purposes, Fig. 1, Plate CX, and one for the high-tension power wires, Fig. 2, Plate CX.

TABLE 13.—Cable Conduit System.

Location.	From:	To:	No. of Power Ducts.	No. of Telephone and Telegraph Ducts.	Total.
North River Tunnels............	Hackensack Portal	Weehawken Shaft	North Tunnel 24	North Tunnel 48	72
			South " 24	South " 48	72
	Weehawken Shaft	11th Avenue Shaft	North Tunnel 15	North Tunnel 40	55
			South " 15	South " 40	55
	11th Avenue Shaft	10th Avenue Portal	North Tunnel 36	North Tunnel 20	56
			South " 36	South " 20	56
	10th Avenue Portal	Terminal Manhole	North Side 36	North Side 21	57
			South " 36	South " 21	57
Terminal Area..	Center of Terminal	Service Plant	184	Pipes from Terminal-Room	
	Center of Terminal	6th Avenue	Tunnel No. 1-30	Pipes in Overhead Gallery	
			" " 2-30		
			" " 3-30		
			" " 4-30		
East River Tunnels............	6th Avenue	1st Avenue Shaft	Tunnel No. 1-30	Tunnel No. 1-48	78
			" " 2-30	" " 2-48	78
			" " 3-30	" " 3-48	78
			" " 4-30	" " 4-48	78
	1st Avenue Shaft	Long Island Shaft	Tunnel No. 1-15	Tunnel No. 1-40	55
			" " 2-15	" " 2-40	55
			" " 3-15	" " 3-40	55
			" " 4-15	" " 4-40	55
	Long Island Shaft	Long Island Portals	Tunnel No. 1-15	Tunnel No. 1-24	39
			" " 2-15	" " 2-24	39
			" " 3-15	" " 3-24	39
			" " 4-15	" " 4-24	39
Long Island City.........	Long Island Shaft	Long Island Power-House	40	....	....

Telegraph Line Poles.—Ultimately, the telegraph and telephone service will require 60 open wires and two 40-pair cables, and it was desired to make this line entirely secure against probable interruption by severe storms or fires in the swamp reeds. The character of the foundation, as indicated, was bad, and, after much consideration, it was decided to substitute for an **H** wooden pole line, which would be inadequate for the conditions, one of concrete poles, which, while somewhat experimental, and perhaps somewhat more costly, would provide a safe and durable construction.

TABLE 14.—POLE LINES.

Description.	Length of line, in miles.	Number of poles.	Length of spans, in feet.	Heights of poles, in feet.	Present installation.	Total future capacity.
Manhattan Transfer Yard: Power-transmission line...........	2.18	40	300	32 to 70	1 ground wire... 4 signal wires....	1 ground wire. 6 power wires. 4 signal wires.
Meadows Section: Power-transmission line.....................	4.60	77	300	50 to 70	1 ground wire...... 9 power wires...... 4 signal wires...... 2 feeder wires.....	1 ground wire. 24 power wires. 4 signal wires. 2 feeder wires.
Meadows Section: Concrete telegraph and telephone poles...	4.60	202	120	35 to 65	34 open wires. ..... 1 telephone cable.. 1 signal cable......	60 open wires. 2 telephone cables. 1 signal cable.
Sunnyside Yard: Signal pole line...............................	0.72	23	150	22 to 45	Varies from 2 to 8 wires.......	2 signal wires. 8 signal wires. 1 signal cable.
Sunnyside Yard: Power and lighting lines.....................	0.13	67	150	34 to 50	Maximum.	1 ground wire. 6 power wires. 2 fire-alarm wires. 4 arc-light wires.

In this section 202 poles were required. They were spaced from 70 to 135 ft. apart, with an average standard span of 120 ft., the variations in span being due to the numerous railway and highway crossings. The heights of the poles above the ground vary from 25 to 50 ft., and they are from 35 to 65 ft. in total length.

The design, made by R. D. Coombs, M. Am. Soc. C. E., Structural Engineer on the staff of the writer, called for transverse loading conditions, in case of maximum storms, equivalent to 6 000 lb. at 6.5 ft. below the top of the pole for the 120-ft. span length. The poles are square in cross-section, with chamfered corners and with a taper of ½ in. in 5 ft. The 1:2:4 concrete mixture of which they are made was assumed to have an ultimate unit strength, in compression, of 2 200 lb. The reinforcement is composed of mechanical bond bars tied together into a square skeleton frame. In the completed pole, this reinforcement is covered by a 1-in. minimum thickness of concrete. The skeleton reinforcement was placed in horizontal frames, and the concrete mixture was poured in and carefully tamped. A special yard (Fig. 1, Plate CXII) was established near the line, in which to make, store, and season the poles. The average number of poles made per day was six, and they were left in place 16 days to season.

After a number of experiments, it was found best to set the poles in pits (Fig. 1, Plate CXI) excavated in the marshy stratum. These pits were generally about 9 ft. square and 5 ft. deep, and a timber grillage was placed around the base of each pole, and about 5 ft. below the top of the ground. This grillage consisted of six track cross-ties bolted together and to the pole, and partly planked over by 3-in. rough lumber. The pole, which projected below the grillage and was pointed at the butt, was jetted down by compressed air into the sandy layer, so that the grillage would rest at the bottom of the pit. The pits were then back-filled with rock and clay. Poles on curves are cross-guyed, and the terminal and railway crossing poles are head-guyed with steel cables. Fig. 2, Plate CXI, shows a pole 55 ft. long, with 13 ft. penetration, and tested by an ultimate load of 4 360 lb. applied horizontally 39.5 ft. from the ground. Subsequent poles were of modified design, giving greater strength.

Because of the unusually heavy line and the extra length required for the foundations, the gross weight per pole, exclusive of grillage

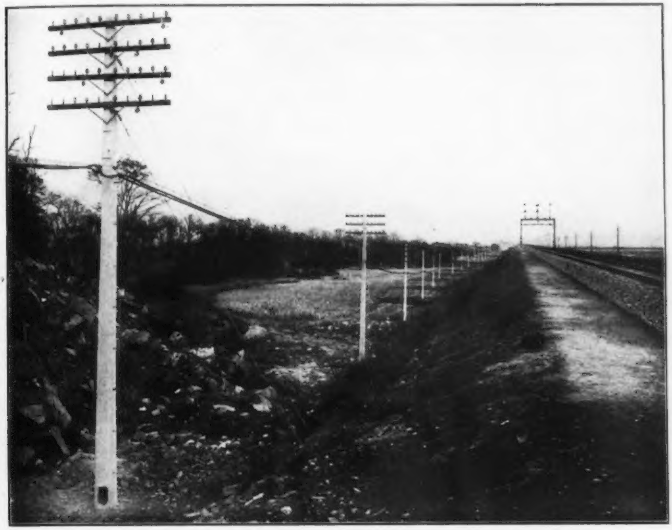


FIG. 1.—CONCRETE POLE TELEGRAPH LINE, MEADOWS DIVISION.

FIG. 2.—POWER TRANSMISSION LINE, MEADOWS DIVISION.

and cross-arms, is more than would be required for ordinary telegraph poles, and varies from 5 300 lb. for a 35-ft. pole to 17 300 lb. for poles 65 ft. in length.

Transmission Line Poles.—As elsewhere described, the wires for the transmission of traction power from the tunnel portal to Harrison Sub-station, and the wires of the high-tension signal power circuits in the same section, are carried on a line of steel poles along the southern edge of the right of way across the Meadows. These poles are set 300 ft. apart, and are designed, not only for the present requirements, but to carry seven additional three-wire transmission circuits which may be required in the future. The total loading called for a very substantial pole construction, and also for foundations to be carried through the soft upper strata of the marsh to a firm bearing.

The poles are of latticed structural steel, square in cross-section, with one angle at each corner and single-angle bracing. The poles have a parabolic outline, conforming to the load requirements and giving an improved appearance. The parabola is of such flat outline that it was not necessary to bend the main angles before assembling. The poles were completely riveted at the shop, with the exception of the cross-arms. The latter consist of single ship-channels with flanges turned downward. The pole has a cast-iron cap at the top, and a section of pipe to carry a 250 000-cir. mil copper ground-wire, which also forms a part of the negative, or return circuit.

In crossing the Hackensack River it was determined to carry the wires overhead rather than by submarine cables, in order to preserve the integrity of the line against lightning disturbances, and to provide for the use of 33 000-volt transmission in the future. For this purpose it was necessary to carry all wires with the clearance specified by the War Department over navigable streams, and this required the use of two unusually high steel towers. The line approaches the river with 300-ft. spans on 50-ft. poles, rising to an intermediate 70-ft. pole, then sharply to the high towers, 181 ft. 4 in. above high water; the lowest wire in this crossing is 137 ft. 4 in. above high water. The wire span over the river has a length of 765 ft. The towers are of the same general outline as the poles, but of much heavier section and larger dimensions. They are 15 ft. square at the base and 3 ft. square at the top. The tops of the foundations are 6 ft. above high

water, and the total height from the water to the ground-wire is 195 ft. The towers are carried on twin-pier, reinforced concrete foundations, each having eleven timber piles under it.

The pole foundations across the Meadows are of concrete on from eight to ten piles, depending on the size of the pole; the piles were driven to a depth of from 30 to 80 ft., as occasion required.

Although the character of the sub-surface strata on the Meadows had been studied from test borings, it was found that the conditions varied radically, and it was not possible, even after driving the piles for one foundation, to determine in advance the approximate length of those for the next (300 ft. distant). This uncertainty added materially to the difficulty of distributing the piles. The cut-off was below the level of the water in the marsh, and, to accomplish this, as well as to place the concrete foundations for the poles in the water-bearing ground, it was necessary to use steel sheet-piling and remove the water with power pumps.

A concrete-mixing train was used for the foundation work; this plant consisted of three cars, the center one containing the mixer with the engine and boiler, and end cars carrying the sand and stone; these cars were provided with steam coils to heat the mixture, as the foundations had to be built in cold weather.

The poles, both of steel and of concrete, were erected with a standard, 75-ton, wrecking derrick, fitted with a special 90-ft. boom capable of lifting either the steel or concrete poles at a point 90 ft. from the center of the track. The concrete poles were lifted from the cars on which they were loaded, and placed on timber horses adjacent to the excavation where they were to be set; the cross-arms and grillage were then put in place, and the pole, thus equipped, was picked up at the top and lowered into the excavation. The steel poles were picked up from the embankment, where they had been unloaded, and lifted by the derrick vertically over the foundation and set in place, as shown by Fig. 2, Plate CXII.

Insulators.—All high-tension insulators are of porcelain, of the petticoat type. Straight-line insulators are made of three pieces, and strain insulators of two pieces. These insulators are mounted on cast-steel pins bolted to the steel channel cross-arms.

Anchoring Devices.—The transmission line poles supporting the spans crossing the various railroads in the Meadows section, and the

FIG. 1.—GRILLAGE FOUNDATION FOR CONCRETE POLE.

FIG. 2.—TESTS OF CONCRETE POLE: POLE 55 FT. LONG; 13 FT. PENETRATION; ULTIMATE LOAD, 4 360 LB., APPLIED HORIZONTALLY 39.5 FT. FROM THE GROUND. SUBSEQUENT POLES WERE OF MODIFIED DESIGN, GIVING GREATER STRENGTH.

city streets in the Sunnyside Yard section, were provided with double cross-arms, strain insulators, and a dead-end clamping device which was designed to attach the power wires securely to the structure.

At the Hackensack River the power line rises sharply, in one span, to the top of the high towers, and required special insulating attachments. Each power wire, in passing over the steel cross-arms of the tower, is carried in a saddle supported by a nest of four standard line insulators. The saddle is provided with a special six-bolt clamp, and its wire groove is curved to prevent sharp bending.

The 2 000 000-cir. mil direct-current feeders, in addition to a similar clamping saddle, have an auxiliary butterfly clamp on each side, about 2.5 ft. from the saddle and attached thereto by adjustable rods.

The high-tension signal power circuits in the Manhattan Transfer Yard are carried on a line of latticed steel poles, extending from the Harrison Sub-station to the Passaic River, at Newark.

Signal Lines.—In addition to the present signal circuits through the yard, and feeding the New York Division at the Passaic River, the pole line is arranged to carry in the future two 3-wire, high-tension, power circuits.

Long Island Railroad Pole Lines.—In Sunnyside Yard the Long Island Railroad traction power line was re-located through the yard and rebuilt from the arrester-house at Dutch Kills Street, to Woodside Avenue, a distance of 8 510 ft. The poles are of the latticed steel type, with straight lines, conforming in design to the original pole line of which it is a part. The cross-arms are of yellow pine, resting on shelf angles, and the attachments to the arms are made by U-bolts to avoid boring holes in the timber.

In Sunnyside Yard the signal power circuits are carried from the tunnels, on a line of light steel poles, to a connection with the Long Island Railroad pole line near Thomson Avenue. These poles are composed of three main members, which are half cylinders of rolled high-carbon steel, fastened together transversely with ties and spreaders.

Two high-tension circuits are carried across the South Yard from the Long Island Railroad pole line to Auxiliary Sub-station "A." The arc-lighting system of the yard is placed on poles of similar design, which also carry the fire-alarm and yard-lighting circuits. Table 14 contains additional data as to all pole lines.

Electric Locomotives.

Quite independently of the general character of the traction system, it was felt that considerable experimental investigation was needed to decide on the type of electric locomotive suitable for handling heavy main-line trains. Therefore a special "Locomotive Committee" was appointed by the President to investigate existing designs and develop, by experiment or otherwise, a suitable locomotive for the exacting conditions of the proposed service. This Committee consisted of A. W. Gibbs, General Superintendent of Motive Power, Pennsylvania Lines East, D. F. Crawford, General Superintendent of Motive Power, Pennsylvania Lines West, A. S. Vogt, Mechanical Engineer, Pennsylvania Railroad, and the writer, as Chairman.

As a result of the work of this committee, two locomotives were designed and built at Altoona in 1905. They were put in service, and given a continuous trial on the Long Island Railroad, hauling freight and passenger trains, and the tests continued for many months. These locomotives are of the double-truck type; the trucks are linked together at their inner ends and the outside ends are used for attachment to the train drawbar. This arrangement of running gear has since been adopted by other roads for slow-speed electric locomotives. Each of the four axles carries an electric motor, one locomotive having geared and the other gearless motors.

These locomotives were designed for a maximum speed of about 45 miles per hour on a level, with a normal train, as at that time it was intended to confine the terminal electric operation to the haul through the tunnels from the west portal at Bergen Hill, New Jersey, to the yard at Long Island City. Practically all this portion of the line is on heavy grades and over a short distance only, and a slow speed would conduce to economy and would not be prohibitive as to time consumed. Subsequently, it was determined to extend the terminal run to Harrison, N. J., on the west, and possibly to Jamaica on the east, involving level stretches of about 10 miles at each end. Hence it became necessary to adapt the locomotives to the higher speed conditions normally obtaining in main-line operation. Accordingly, the two locomotives under test were modified electrically to permit of a maximum speed of about 65 miles an hour. Tests with these machines had demonstrated their hauling power and successful operation at the slow speed for which they were originally designed, but when speeded up it was

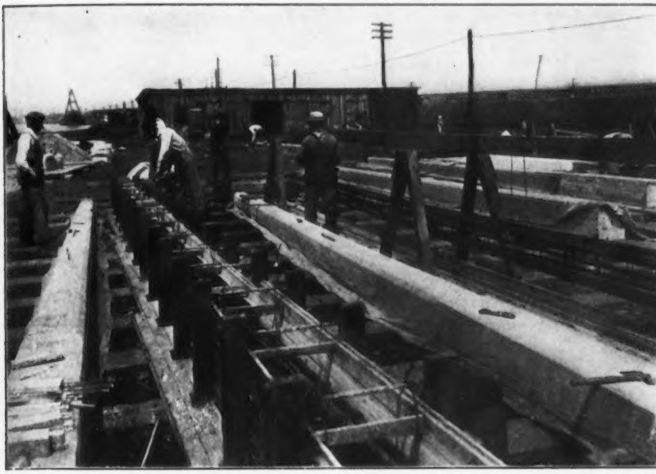


FIG. 1.—CONCRETE POLES IN PROCESS OF MANUFACTURE.

FIG. 2.—SPECIAL 90-FT. BOOM DERRICK ERECTING STEEL POLES ON MEADOWS DIVISION.

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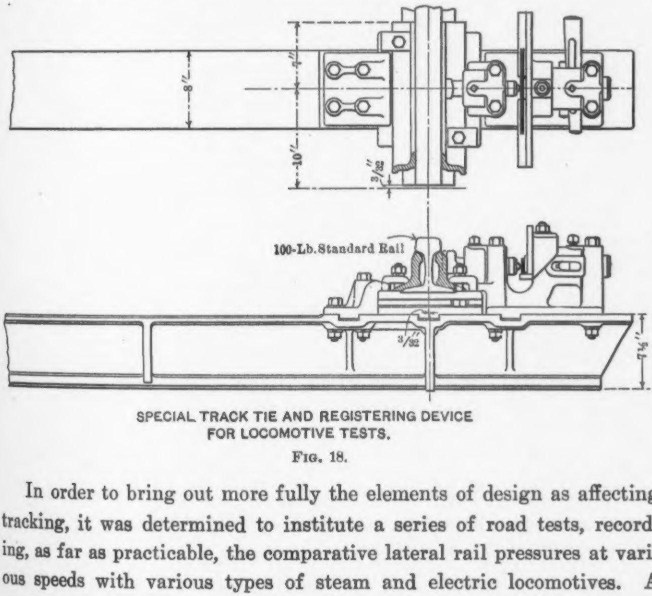
found that they became quite destructive to track. At speeds greater than 45 miles per hour they developed a tendency to rhythmic side swaying and the production of excessive lateral pressures at the rail heads. Such peculiarities in steam locomotives, with low-hung boilers, of course, were not altogether unknown to railway engineers, but they are intensified in an electric locomotive, where the power is applied with extreme compactness, and where a convenient method of motor attachment concentrates great weight around the axles; also, where it is not only possible, but generally most convenient, to utilize all weight for adhesion. Fig. 1, Plate CXIII, shows the motors and running-gear, and Fig. 2, Plate CXIII, is a view of an articulated electric locomotive.



SPECIAL TRACK TIE AND REGISTERING DEVICE FOR LOCOMOTIVE TESTS.

FIG. 18.

In order to bring out more fully the elements of design as affecting tracking, it was determined to institute a series of road tests, recording, as far as practicable, the comparative lateral rail pressures at various speeds with various types of steam and electric locomotives. A special recording apparatus (Fig. 18) for the purpose was devised and placed in a stretch of tangent track on the electrified portion of the West Jersey and Seashore Railroad. A complete series of tests was made, and, from the information obtained, the mechanical characteristics of the design of the locomotive to be built for tunnel operation were determined. During 1910 this test apparatus was again installed, this time in a section of the Terminal division track, and the new

locomotives were tested thereon to check their actual with their expected performance. The test was made over a length of 165 ft. of special track carried on cast-steel ties, having chairs near their ends for holding the rails. The chairs rest on rollers on seats in the ties, and allow for free lateral motion outward of the rails, except as restrained by the pressure-registering device on each tie. This device is in the form of a plug carried in a guide on the chair-seat casting; at one end it presses against the side of the rail head and at the other it carries a hardened steel ball which is placed in contact with a strip of plate steel. Proper adjustment for gauge is made before each run by wedges between the plugs and rails. Any side pressure at the rail from the wheel flanges of a locomotive moving over the track causes the steel

RIDING QUALITIES OF LOCOMOTIVES
WITH RESPECT TO TRACK ON TANGENT

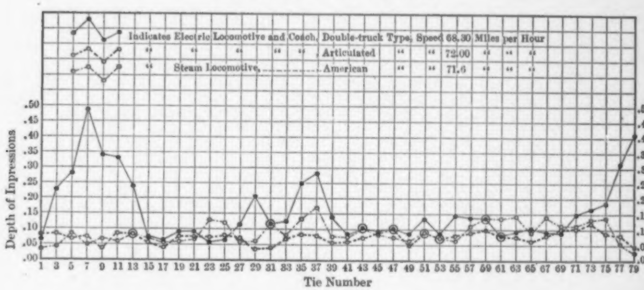


FIG. 19.

balls to press into and indent the steel-plate strips. The diameter of the impression, when measured by a micrometer microscope, indicates the magnitude of the side pressure, the location of the maxima, and the tendency of the locomotive to "nose" or oscillate. Typical samples of the records obtained along this track section are given in Fig. 19, one showing a normal record from a steam locomotive of the Atlantic type; another, from the original design of electric locomotive, and a third from the adopted type of electric locomotive. The tests were conducted to show the free-running characteristics of the locomotives at speeds as high as 94.6 miles per hour with a steam locomotive, and 86 miles per hour with an electric locomotive.

To test the pressure of individual wheels on curves, especially as affecting behavior in taking switches and turn-outs in yards, a hydraulic

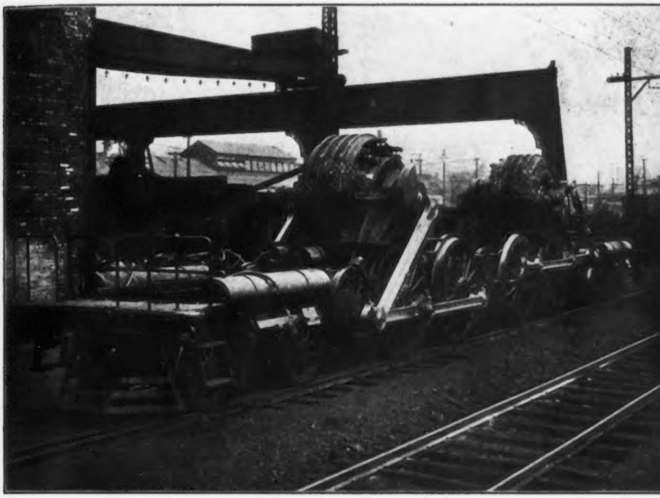


Fig. 1.—Electric Locomotive, Showing Motors and Running Gear.

Fig. 2.—Articulated Electric Locomotive.

apparatus devised by Mr. George L. Fowler was used. With this device the side pressure of each wheel flange is measured by connecting a short section of one rail through a system of levers to a hydraulic cylinder and its pressure-recording device. From experience obtained in the service tests of three different types of electric locomotives, and the results of the special track instrument tests, it was decided to make quite a radical departure from general practice in the final design of the high-speed locomotives for the terminal equipment. An attempt has been made to pattern the locomotive mechanically on the fundamental characteristics of modern steam locomotive design in the following particulars:

(*a*) High center of gravity of the machine as a whole, and especially of the heavy electric motor portion;
(*b*) The large proportion of the total weight spring-borne, and equalized by a system having considerable amplitude of motion;
(*c*) An unsymmetrical distribution of wheel-base of the locomotive;
(*d*) A combination of driving and carrying wheels.

DIAGRAM OF ELECTRIC LOCOMOTIVE.

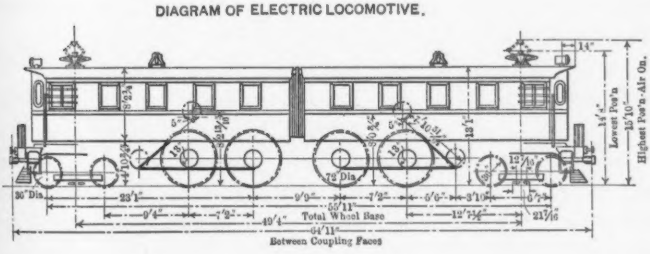


Fig. 20.

All the above characteristics, it was thought, would conduce to ease of riding, flexibility in tracking, and the reduction of destructive action to the roadbed by heavy masses moving at high speeds.

To accomplish these results, required an important modification in the customary method of mounting and connecting the electric motors; instead of being placed concentric with or in the plane of the axles, and direct-mounted or geared to them, they are placed on the main frames above the wheels, and driving connections are made with rods. The diagram, Fig. 20, and the photographs, Plate CXIII, show the general features of the design and the principal dimensions. The locomotive is double, or articulated, each half being similar to an "American" type,

or eight-wheeled steam locomotive, in the wheel arrangement, frames, and running gear. These halves are permanently coupled back to back by a drawbar and equalizing buffer connection. Each half has its own cab, and carries above the frame one series-wound electric motor, having inter-poles and a divided main-field winding. The large space available for the motor enabled its design to be liberal in all parts, and its location makes the entire motor accessible for inspection. The motor shaft, or axle, carries quartered cranks which are connected by rods to a cranked jack-shaft set between the frames and having its center in the plane of the driving axle center. From this shaft, rod connections are made to the wheels, as in steam locomotives. All moving masses of the rods and cranks are revolving, and are susceptible of accurate counterbalancing. The system adopted for motor control enables one motor to be out of service and the locomotive to be operated in emergency by the remaining motor; also, two or more locomotives may be coupled together and operated as a single unit. The division of the fields into sections for manipulating the field strength, gives four, instead of the usual two, running positions of the speed controller, and thus, also, economizes current during acceleration.

Special attention has been given to the arrangement of control and other apparatus in the locomotive cabs, to enable all parts to be readily accessible for inspection and adjustment, such as electrically-driven air pumps for brakes and control, pneumatic sanding devices, contact shoes for the third-rail, overhead pantagraph shoes, sleet-scraping devices for removing ice and snow from the third-rail, automatic train stops for applying the brakes and shutting off power in case of over-running signals in the tunnels, etc. The locomotives are also equipped with boilers for steam generation by electrically heating the water in the boiler to supply the steam-heating system of the trains.

In fixing the capacity of the locomotive, the probable maximum and average train weight was established, and the unit was designed for the most economical distribution of equipment for the Terminal service. It is obvious that on a short run the condition of starting a train from rest and accelerating on the tunnel grades fixes the maximum train which can be hauled, rather than the limitation of motor capacity due to the heating. The maximum weight of train to be hauled by one locomotive under the given conditions was specified as 550 tons trailing

load; the actual capacity, however, in intermittent service, has approximated 700 tons trailing.

A sample locomotive of this design was built, placed under road test in October, 1909, and run 15 000 miles on a continuous test, with a train of 400 tons trailing; also, complete dynamometer-car tests were made of the hauling capacity, speed, and motor characteristics. The detailed design of the mechanical portion of these locomotives was made by the Motive Power Department at Altoona, and the running gear and cabs were built complete at the Juniata shops.

In speaking of this development, it is not out of place to refer to the part taken by the Westinghouse Electric and Manufacturing Company, the contractor for the electric apparatus of the locomotives. From the first this company not only co-operated with the Committee in all needful respects in furnishing suggestions and information, but built at its own expense the electrical portions of the first two electric locomotives, and subsequently a complete locomotive of another type, all of which it placed at the disposal of the Committee for service and other tests.

The principal dimensions, weights, etc., of the adopted type of locomotive are:

Weight per driving axle..................		48 750	lb.
Total weight on drivers..................		195 000	"
Weight on each 4-wheel truck............		57 500	"
Total weight of complete locomotive......		310 000	"
Total length over all....................	64 ft.	11	in.
Rigid wheel-base of each half............	7 "	2	"
Total wheel-base of each half............	23 "	1	"
Total wheel-base of locomotive...........	55 "	11	"
Diameter of drivers......................		72	"
Diameter of truck wheels.................		36	"
Height from track to top of cab..........	13 "	1	"
Width of cab.............................	10 "	6	"

The weights do not include the electric steam generators for train heating. The tractive effort per locomotive = 60 000 lb. for ½ min., and 50 000 lb. for 2 min., or 12 000 lb. at 800 amperes, all with full field. One of the conditions was that the locomotive was to start and accelerate a 550-ton train, in addition to the locomotive, on the 1.93% maximum tunnel grade, and, with a 550-ton train on level tangent track, was to attain a speed of 60 miles per hour. Each locomotive was to have

two direct-current, field-controlled, inter-pole, series motors, with cast-steel frames.

Weight of each motor complete with cranks.	43 000 lb.
Height of center of gravity from track.......8	ft. $2\frac{13}{16}$ in.
Top of motor frame above cab floor.........5	" $6\frac{1}{2}$ "

Table 15 is a comparison of the centers of gravity and the weights of electric and steam locomotives.

TABLE 15.—Comparison of Electric and Steam Locomotives.

	Experimental, double-truck electric.	Adopted articulated electric.	P. R. R. "Atlantic" type, steam.	P. R. R. "American" type, steam.
Total weight (excluding tender), in pounds.	195 140	310 000	176 600	138 000
Height of center of gravity of complete locomotive, from rail, in inches	42.5	63.75	73	63
Height of center of gravity of running gear, from rail, in inches	*28.0	30.2	33	29
Percentage of weight of running gear below springs to total weight	*50.0	16.7	22.7	22.7

*Includes weight of motors.

Telephones and Telegraph.

Telephones.

The telephone system comprises a complete installation for official and public uses, and was planned jointly by the Telegraph Department of the Pennsylvania Railroad Company and the New York Telephone Company.

Official Equipment.—The official equipment provides for service between the various Departments of the Terminal Division and of the Long Island Railroad. It consists of a main private branch exchange switch-board having trunk lines to the Telephone Company's general exchange system; tie lines to other private branch exchanges in the various offices of the Railroad Company in New York and other cities; extension lines to the various offices of the Terminal and Long Island Railroads in the Station Building; and a special switch-board for the Information Bureau of the Station, by which calls from the public for information as to arrival and departure of trains are received and answered with the minimum of delay.

The main private branch exchange switch-board in the Station has a capacity of 1 000 lines. It is equipped initially for 520 lines, the following being connected at the present time:

40 Trunk lines to Telephone Company's central exchange;
80 Tie lines to the Railroad Company's offices in New York and Philadelphia;
80 Magneto extension lines to the Signal Cabins and Yard Buildings;
260 Battery extension lines for offices in the Station Building.

The board is arranged for 6 operators, with all connections in multiple; it connects with 25 monitor boards, varying in capacity from 10 to 30 lines, and located in the Power-House, the Sub-stations, and the Signal Cabins. In signal cabins where there is more than one board they are in multiple, so that one or all of them can be used to respond to the calls. The Train Dispatcher, having a selector bell-ringing circuit, may call up any one of the interlocking cabins without calling the others, or he may call them all in multiple, and talk to all at the same time.

In addition to the above, a system of magneto-telephones is provided for direct calls through these switch-boards from outlying points on the Terminal Railroad, such as the signal bridges on the Meadows Section, and from each signal in the tunnels. In all, 140 points on the railroad are thus provided with magneto-sets.

Tunnel Sets.—The tunnel sets have been especially designed to be placed conveniently and compactly on the tunnel walls above the side-benches; they consist of magneto-sets in special moisture-proof cases. A key with each set permits of its connection to any one of four circuits extending through the tunnels; one to the main private branch exchange switch-board, a second to the Power Director's monitor-board, a third to the interlocking cabin controlling movements on the section in question, and a fourth is spare. There are 53 of these sets at an average of about 1 500 ft. apart in the tunnels. In addition to the four circuits above mentioned, there is a fifth circuit in each tunnel to which are connected a number of loud-ringing gongs for signalling employees, who may be called to the nearest telephone, by a code signal.

Pay-Station Service; New York Telephone Company.—The pay-station service is of three kinds. First, the standard service, where a patron makes a call from a booth; this is handled through switch-

boards and booths in the main waiting-room, the sub-waiting-rooms, the exit, and the Long Island 33d Street concourses. Second, a restaurant pay service, where a patron makes a call from a table while dining. Third, train pay-station service, by which a call may be made from a telephone in a train standing at a station platform. For this latter purpose there are receptacles at convenient points under the platforms, and flexible cable is used for connecting to receptacles on the car.

Installation.—Leaving the main switch-board in the Station, four cables, a 30-, a 50-, and two 15-pair, copper-wire, paper-insulated, lead-covered cables, are run in the yard and tunnel conduit systems to the Hackensack Portal. From a terminal pole at this point 34 open copper wires and a 40-pair cable are carried on the concrete pole line over the Meadows Division to Harrison Sub-station. These lines pass under the Hackensack River by submarine cables. From Harrison Sub-station, connections are made to the New York Division lines to Philadelphia, and through "GY" interlocking cabin to Jersey City; also to the cabins in Manhattan Transfer yard. All open wires are No. 8 and No. 9, B. & S. gauge, copper, and are transposed on the poles at frequent intervals. The cable lines are No. 13 and No. 16, B. & S. gauge, copper wire.

Eastward from the Station, a 15-pair cable runs in each of the four tubes, and in one tube (No. 4) a 110-pair cable runs to the Long Island City shaft, at which point it divides to run to the main power-house and to Sunnyside Yard. In Sunnyside Yard a complete service is provided to the various yard buildings and interlocking cabins. The New York Telephone Company's cable connections are made with the Chelsea Exchange, through cables brought out at a telephone manhole in Eighth Avenue, near 31st Street, and, in addition, two ducts in the East River Tunnels have been leased by the Telephone Company for service on Long Island.

Ringing current for the switch-boards throughout is supplied by the Telephone Company from their City Exchange, but the telephone-operating current is obtained from storage batteries charged by motor-generator sets in the Station, converting 440-volt alternating to 24-volt direct current.

The cables, the pole-line wiring, and the tunnel sets were installed by the Chief Engineer's Department, and the switch-boards and instruments by the Telephone Company.

Telegraph.

The telegraph system was planned by the Telegraph Department of the Pennsylvania Railroad; it connects with the general system of that Road and of the Long Island Railroad, and includes, for the convenience of the public, Postal Telegraph Cable Company's connections and offices in the Station.

A main telegraph office on the second floor of the Eighth Avenue side of the Station is equipped with a two-section, twenty-five lines each, double-jack switch-board, with the necessary lamp-receptacle resistance-panels to the batteries. The power-room is back of the board, and comprises duplicate motor-generators, with batteries, for furnishing power to the lines, the train describers, local sounders, and other low-voltage circuits. The board is laid out for three 6-position telegraph tables, of which two are now in service, and the through wires from the various Pennsylvania Railroad and Long Island Railroad offices connect with them. These wires are used for messages, train reports, and general information. A separate board is also provided in the Station Master's office, and consists of one 12-circuit, single jack-board and 4-position table.

In order to reduce the number of telegraph offices in the Station and yard, the pneumatic tube system, elsewhere described, connects with the main telegraph office, to which messages may be sent for transmission. For the use of the heads of the Departments in the Station, a message-call service, consisting of a 50-needle, individual, set-back annunciator, has been installed in the main telegraph office.

It was at first planned to conduct train movement by telephone, but after due consideration, on account of the new operation involved, and the fact that it was desired to select experienced "block" men, who were telegraph operators, from the existing portions of the railway system, it was thought best to provide them with telegraph block wires, by which means the Chief Train Director could hear all orders over the circuits. A relief telephone block circuit, however, is provided over the Meadows Section, to be used when the telegraph block wires are busy, or when repairmen wish to communicate with each other between interlocking cabins.

Allied to and supplementing the telegraph system, instruments called "train describers" are used in the interlocking cabins from Newark, N. J., to Winfield, Long Island. They constitute a mechanical

telegraph system, registering by disks on dials different train designations and routes. Each instrument has sixteen disks, for as many designations, and one set of instruments is used for in-bound and another for out-bound movements.

Telautograph System.—For the purpose of transmitting messages or orders in written form as a matter of record, or to supply advance information of train movement simultaneously to various offices and interlocking cabins, the Gray telautograph system, with 3 transmitting and 17 receiving stations, has been installed in the Station. The transmitting instruments are in the Train Dispatcher's office, in the main interlocking cabin ("A"), controlling the west throat of the terminal yard, and in interlocking cabin ("B") controlling Long Island Railroad movements. Instructions as to special train make-ups, changes in destination platforms, etc., are thus given to all parties interested, with minimum loss of time. In order to be certain that the message is received, an answer-back system is provided; this is operated by push buttons and bells in the receiving stations and a needle annunciator at the transmitting station. Electric power to operate the telautograph and call-back systems is furnished from the motor-generators in the main telegraph office.

Signalling.

As the rapid movement and safe control of trains over the Division, and especially in the Station Yard, are essential to the regular and safe operation of the railroad at its required capacity, the switch and signal system was made unusually complete. The general requirements were laid down by the "Joint Operating Committee," through a Sub-Committee on Signals appointed by it, for the purpose of giving the question the necessary detailed study. This latter committee consisted of Messrs. A. H. Rudd, Signal Engineer, George D. Fowle, Consulting Signal Engineer, C. S. Krick, Superintendent, with the writer as Chairman. A general contract was entered into with The Union Switch and Signal Company for the manufacture and installation of the system, under the supervision of Mr. W. N. Spangler, Supervisor of Signals, in the Chief Engineer's Department.

Yard Conditions.—The physical conditions surrounding the Station Yard are exceptional in the following respects:

(*a*) The yard is practically underground, and the view from trains, and of the tower operators, is obscured by numerous yard structures and building columns;

(*b*) Clearances, both overhead and side, between the trains and structures are very limited, and the space available for the installation of signals and apparatus is restricted;

(*c*) The character and extent of the train movements required the realization of the fullest capacity of all track facilities, necessitating the greatest freedom for simultaneous parallel movements;

(*d*) The complexity of the track plans and the presence of yard service facilities, such as the piping system for steam, air, and water, drainage and traction conductors and conduits, required that the signal appliances should be mounted on special foundations, and that control wiring should be run in permanent and accessible shape in a conduit system.

On account of these conditions, it was found necessary to divide the control of the yard movements between four different power-operated switching cabins; one near the west end of the yard, for movements from the North River Tunnel portals to Eighth Avenue; one near, and east of, Eighth Avenue, north side, for the important tail switching for Long Island Railroad suburban trains; one at the Seventh Avenue portal of the 33d Street Tunnels, where the yard tracks are gathered into groups leading into two of the East River Tunnels; and one similarly located under Seventh Avenue at the throat of the 32d Street Tunnels. These cabins, each controlling only a part of the yard, required a certain amount of interconnection to insure rapid and complete movements in the yard, a result accomplished partly by electric locking between cabins, partly by light indicators on the track models in the cabins, to show how the tracks between them are occupied and when trains are approaching, and partly by central communication by telephone, etc., with the Train Director.

The interlocking machines comprise means for obtaining positive control of all signals by the actual position of the switches which they govern; the automatic control of signals by track conditions in advance of them, and by the position of the next succeeding signal to which the impending train movement leads; the automatic locking of all switches in every route by the entrance of trains on these routes, and the automatic release of switches immediately in the rear of a train passing clear of the fouling points. They, further, include means for giving

visual indications to the operator of every act of a train in physically locking and releasing the levers controlling switch and signal operations; means for permitting the joint use of all tracks for traffic in either direction between adjacent cabins by co-action of towermen and track circuits; the automatic announcement of trains in their approach to the terminal station through the various tunnels, and the delineation of their movements from block to block through the tunnels, by indicators in each cabin adjacent to the tunnel portals.

Tunnel Conditions.—The tunnels, as elsewhere shown, involve train movements over heavy grades, at high speed, and at the minimum safe interval, a condition which led to the adoption of automatic block signalling with overlaps of the same length as the block sections; in other words, a two-indication block in which a "proceed" indication requires that two sections shall be unoccupied. "Caution" indication must show that at least as much track is unoccupied as the foregoing. The length of the sections is variable, depending on the grade and maximum train speed at the point in question, being made 150% of the length in which a stop can be made by the application of the brakes.

At each block in the tunnels a "track stop" is installed to apply the train brakes automatically should a danger signal be over-run. The closest headway at which trains can be run at normal speed, therefore, is the time required to pass over two block sections, corresponding to about 2 min., and at restricted speed under caution signals, one block, or about 1½ min.

"Lock and block" control has been provided between the Station and the Long Island approach of the East River Tunnels, so that, if necessary, any one of the four tunnel tracks can be operated in the reverse direction. The North River tunnels have the same provision, with the addition of automatic signals for following movements. The grades are such that the spacing of signals for reverse movements could not be the same as for movements in the normal direction of traffic, and, on account of this, there was considerable complication in putting the signals for a certain direction out of commission and those for the opposite direction in, and changing the control of the automatic stops so as to make them effective at the right time.

Meadows Section.—The Meadows Section of the road (Plate CXIV) has been equipped with automatic block signals, according to the same principles as those for the tunnels, without track-stops. Complete reverse-movement signalling has been provided for at each block. At

DIAGRAM OF TRACKS AND SIGNALS, MANHATTAN

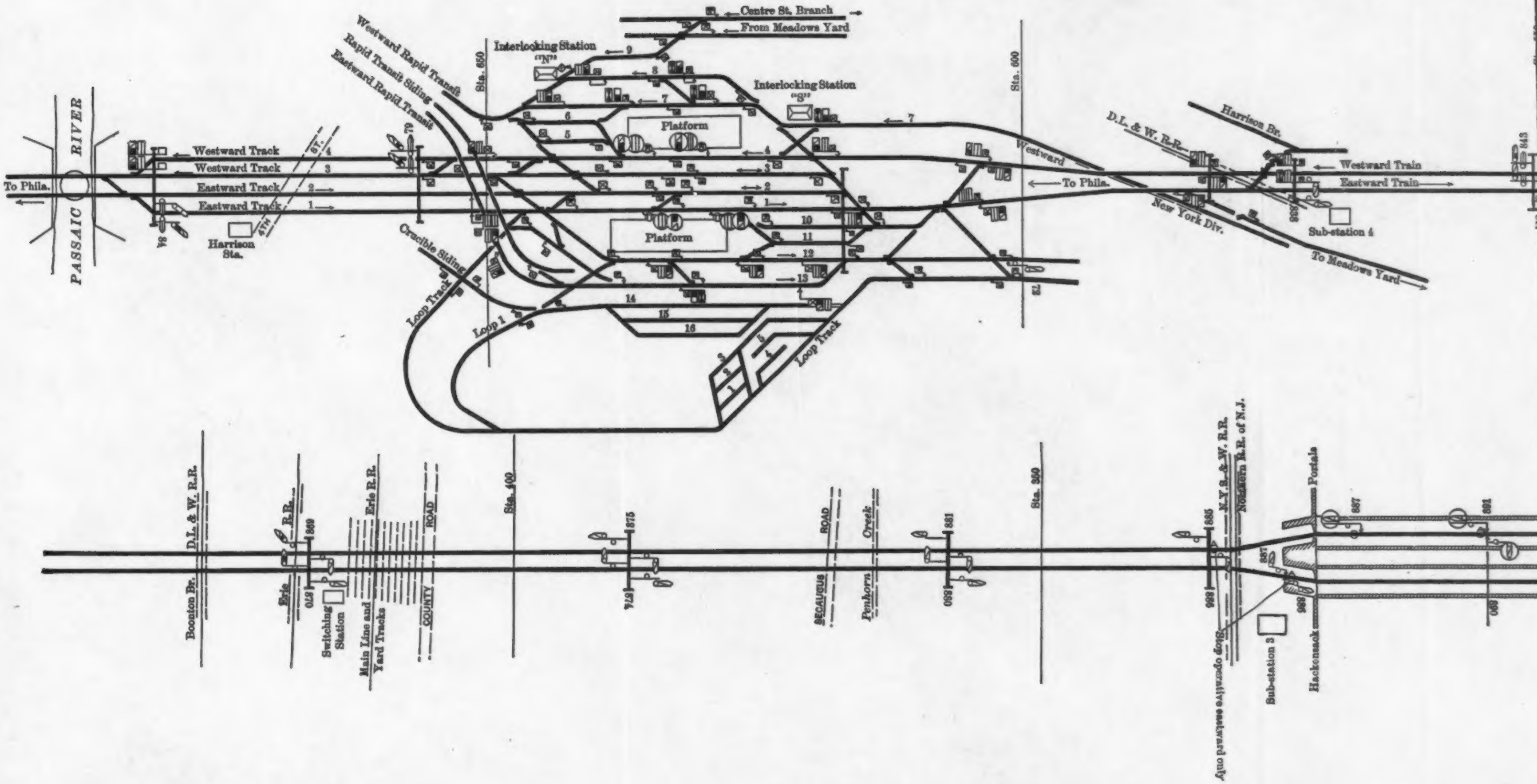


DIAGRAM OF TRACKS AND SIGNALS, MANHATTAN TRANSFER TO TENTH AVENUE.

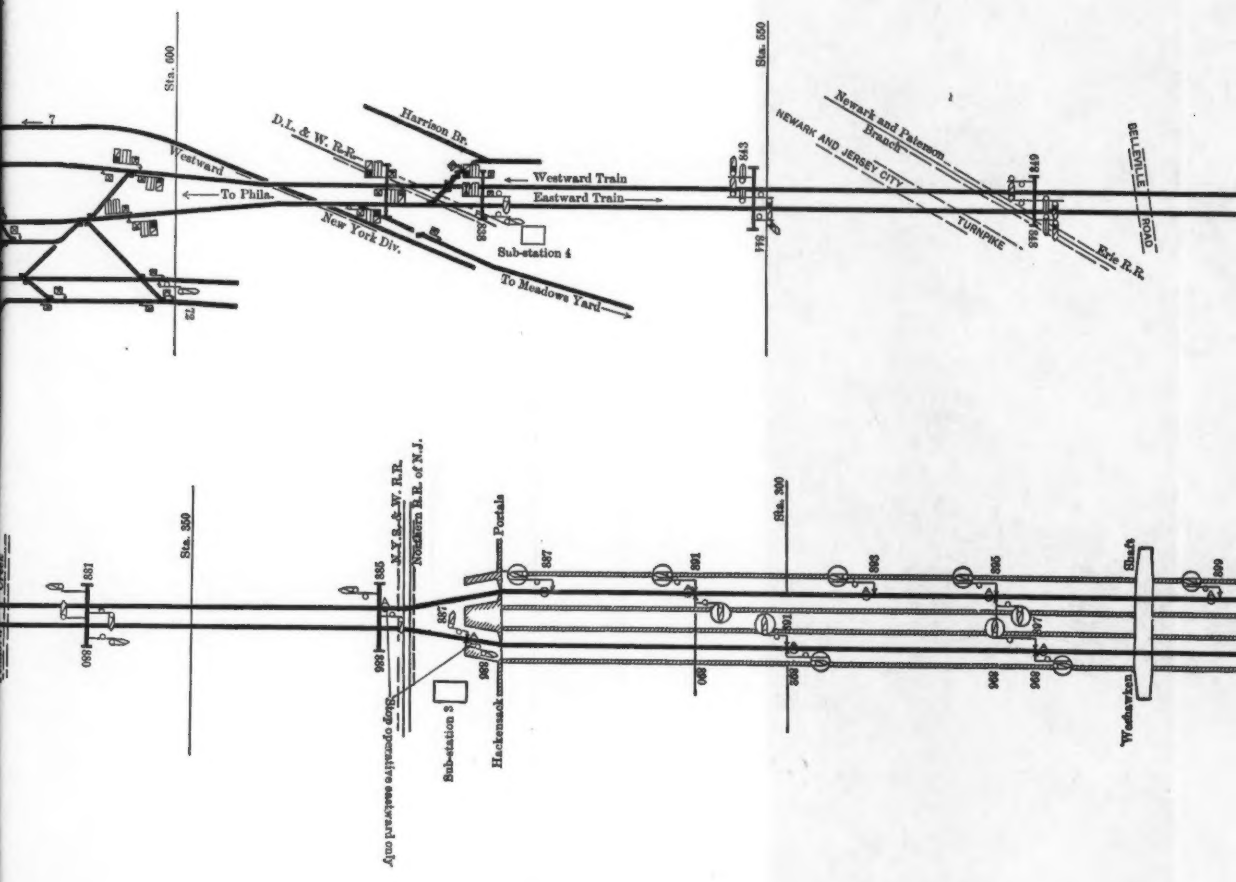
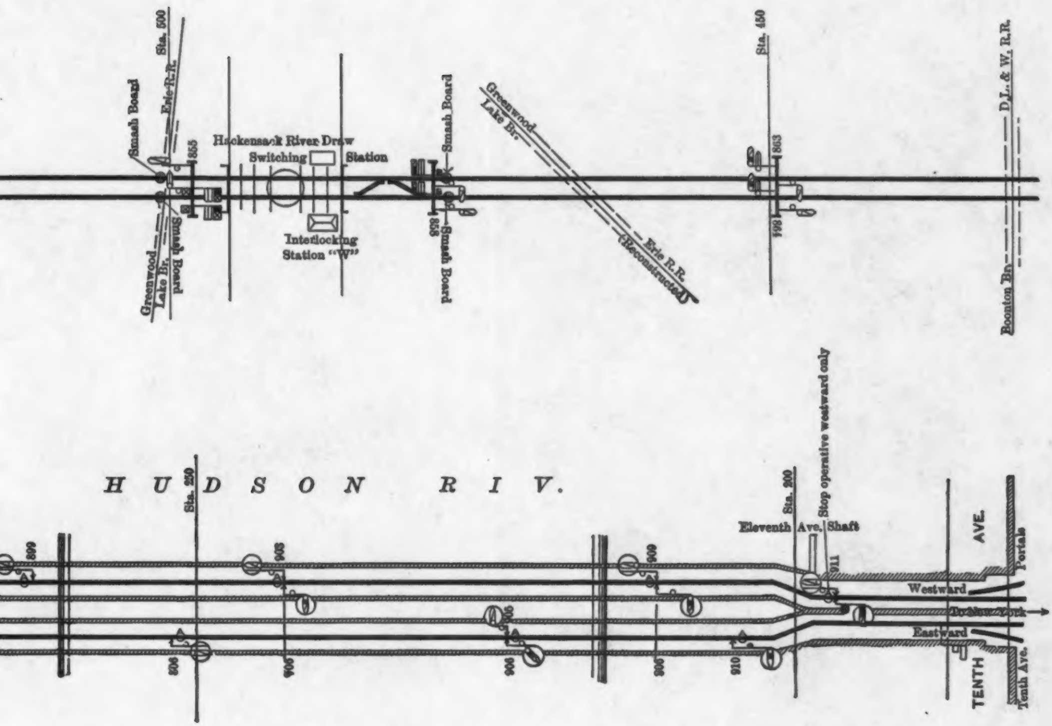


PLATE CXIV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1165.
GIBBS ON
PENN. R. R. TUNNELS: STATION, TRACK, YARDS, ETC.



the Hackensack River, midway of the section, the drawbridge has been provided with the usual interlocking bridge and signal appliances, and the cross-overs between tracks at the east approach to the bridge, so that reverse movements may originate either east or west from this point.

Outlying Yards.—At Manhattan Transfer, where the interchange of steam and electric power, and the Rapid Transit connection to Jersey City and the down-town district of New York, are made, two very complete electro-pneumatic interlocking plants are provided, controlling all main-line switches from the Passaic River to the separation of the New York and the Terminal Divisions at the east end (Plates CXIV and CXV). These interlockings required considerable complication of circuit work to permit of high-speed operation through the yard with sufficient advance information for the control of movements.

At Sunnyside Yard (Plate CXVI) four interlockings were required, two for main-line movements to and from the tunnels and for the Long Island Railroad movements through the yard, and two for switching in the yard proper.

Type of Signals.—The "Rudd and Rhea" arrangement has been adopted for the signal arms and lights. A signal consists of a 3-position arm to combine the functions of two signals having but two positions each, with the movements of the arm from horizontal to vertical through the upper quadrant. The fact that the signal is automatic is conveyed by pointing the blade for day indication and by a fixed light underneath, staggered in position, for night indication. Interlocking signals are multiple-arm, with square end and vertical lights; the top arm for high speed, the second for limited speed, and the lower one, or a dwarf signal, for low speed. In the Station Yard (Plate CXV) one-speed signalling only is used; that is, a high-speed arm permits movement at the highest permissible speed and a lower or "calling-on" arm is provided for use only when a "proceed" indication cannot be given by the normal (or upper arm), or for movements to the storage yard or stub-end tracks.

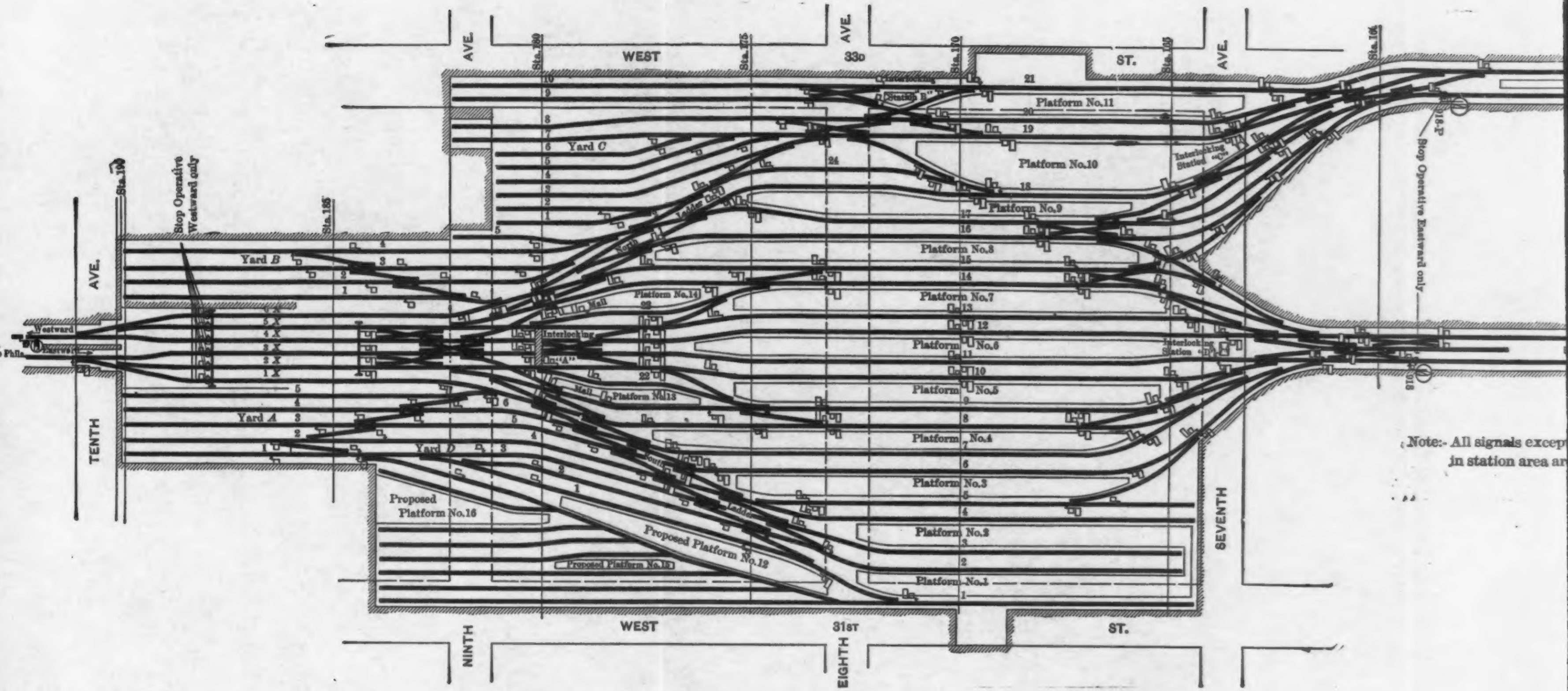
Because of the absence of daylight conditions in the tunnels and in the covered portion of the Terminal area, the use of signals having arms for defining their positions became of secondary importance, and this fact, coupled with close clearances encountered, prompted the total elimination of the arms from all block signals in the tunnels, and from all but the ground or dwarf signals in the Station area, the indi-

cations being given entirely by lights. This signal contains no mechanism other than that required for changing the colors of stationary lights in such a manner as to reproduce the same colors and combinations as called for by changes in position of a semaphore signal under like conditions in the controlling currents. The signals are cast-iron receptacles carrying colored lenses, behind which are located standard 4-c.p. incandescent lamps (two in multiple for each lens), and the mechanism consists of relays, housed in separate shelters near the signals, the contacts of which are adapted to shift the current from lamp to lamp, and thus change the colors displayed as the relays are energized or de-energized by manipulation of the machine levers, or by the action of trains on track circuits, or by both. These relays operate by alternating current in the signal circuit of the track rails, and are in some cases of the pneumatic pin type actuated by A.C. motors, where connected to the track-stops, and in others of the straight A.C. type, where signals alone are controlled; both types have multiple contacts, numbering from two to fifteen, as occasion requires.

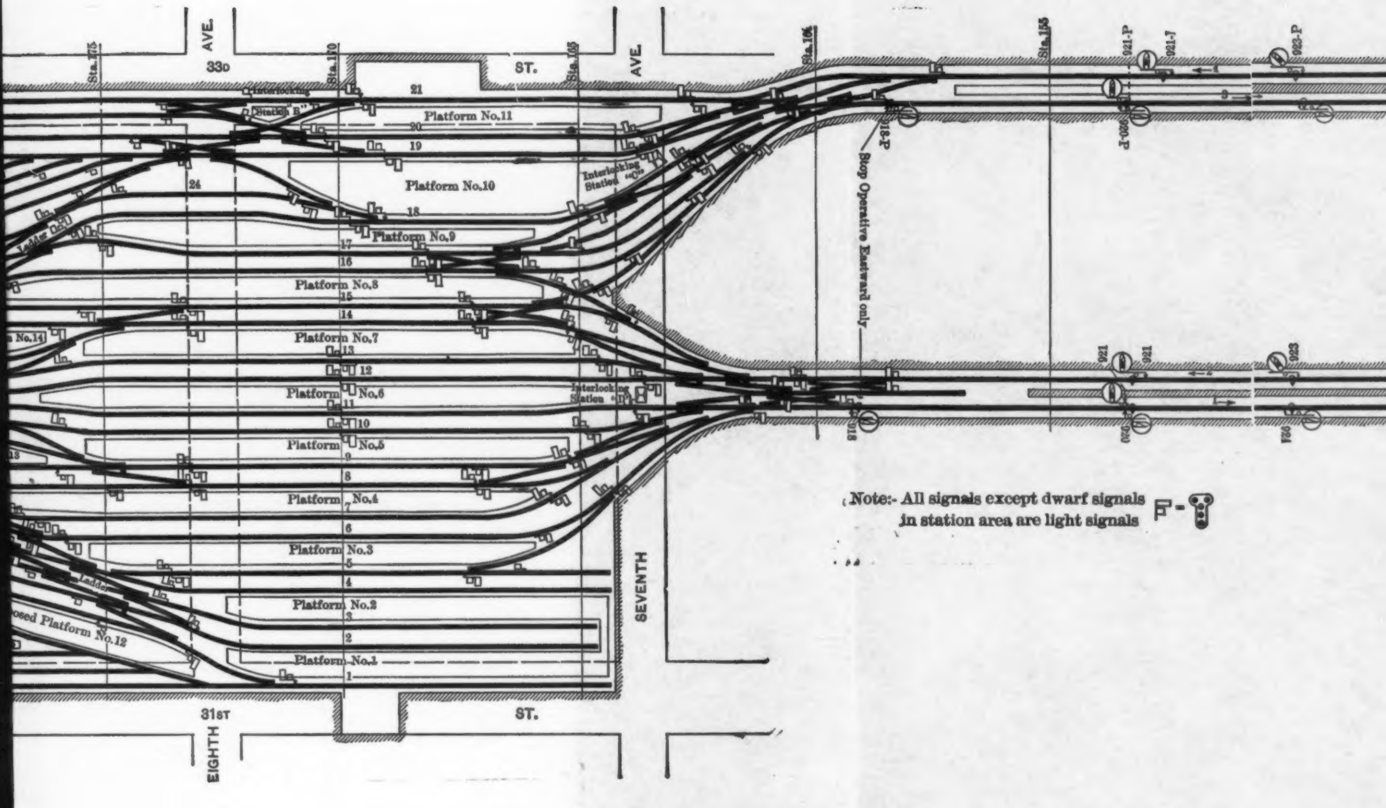
Because of the difficulty of obtaining ample clearances and suitable supports for semaphore signals in the yard, and in order to maintain a uniform type of signal within the Station area, special hooded lenses and lamps of high candle-power are used in the "lamp" type of signal in these exposed places, and are found to give effective indication for the possible range of observance. Elsewhere on the line, outside of the terminal and tunnels, this form of signal would not prove satisfactory because of the higher speeds and longer range of observation required; therefore, the semaphore type is used on the open line.

Circuit Control.—The control of all signals, block or interlocking, is secured automatically by track circuits. In the Station Yard various functions were required of these circuits, to permit of the most flexible train movements under the obscure physical conditions. They may be classified as follows:

(*a*) Circuits used as a substitute for detector bars;
(*b*) Circuits for switch and signal control;
(*c*) Circuits for route locking, where trains passing home signals electrically lock, in advance, the levers of all switches over which they are to pass, and release the levers for subsequent movements when the point of clearance to the switches has been passed;
(*d*) Circuits for indication on the track models in the cabins.



WEST 33D ST.
WEST 31ST ST.
TENTH AVE.
NINTH AVE.
EIGHTH AVE.
SEVENTH AVE.
Sta.190
Sta.185
Sta.180
Sta.175
Sta.170
Sta.165
Sta.164
Stop Operative Westward only
Stop Operative Eastward only
Westward
Eastward
To Phila.
Yard A
Yard B
Yard C
Yard D
Interlocking Station "A"
Interlocking Station "B"
Interlocking Station "C"
Platform No.1
Platform No.2
Platform No.3
Platform No.4
Platform No.5
Platform No.6
Platform No.7
Platform No.8
Platform No.9
Platform No.10
Platform No.11
Platform No.13
Platform No.14
Proposed Platform No.12
Proposed Platform No.15
Proposed Platform No.16
Mail
Note:- All signals excep
in station area ar


AVE.
33D
ST.
AVE.
Sta.175
Sta.170
Sta.165
Sta.160
Sta.155
Interlocking Station "B"
Platform No.11
Platform No.10
Platform No.9
Platform No.8
Platform No.7
Platform No.6
Platform No.5
Platform No.4
Platform No.3
Platform No.2
Platform No.1
Proposed Platform No.12
Interlocking Station "C"
Interlocking Station "D"
Stop Operative Eastward only
918-P
921-P
921-7
923-P
920-P
921
923
SEVENTH
EIGHTH
31ST
ST.
Note:- All signals except dwarf signals in station area are light signals

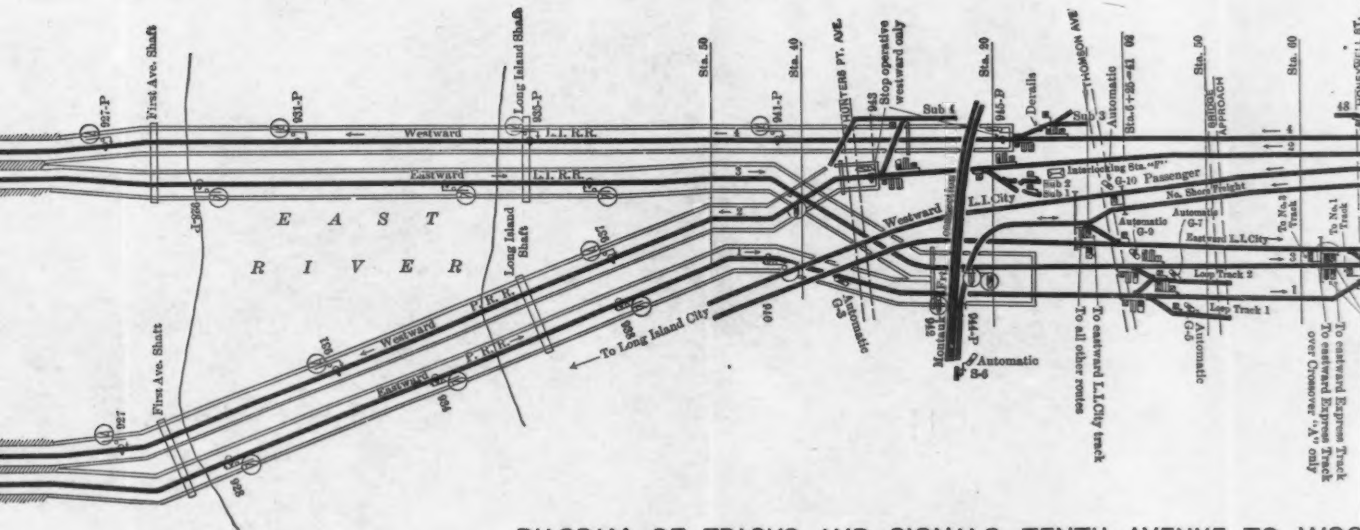


DIAGRAM OF TRACKS AND SIGNALS, TENTH AVENUE TO WOO

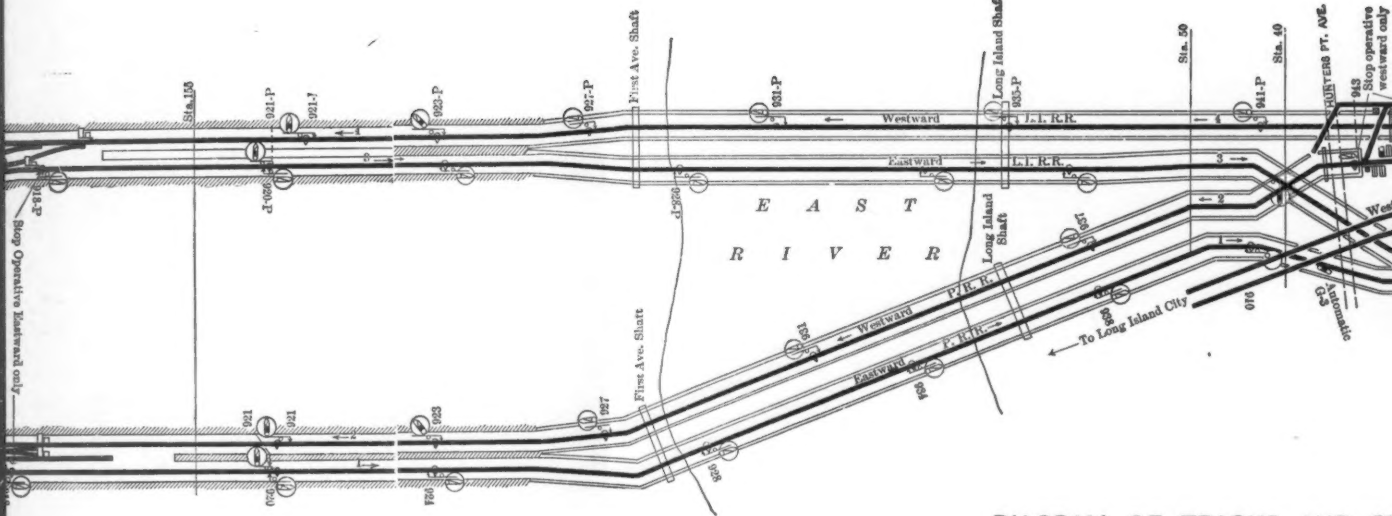


DIAGRAM OF TRACKS AND SI

Note:- All signals except dwarf signals in station area are light signals

PLATE CXV.
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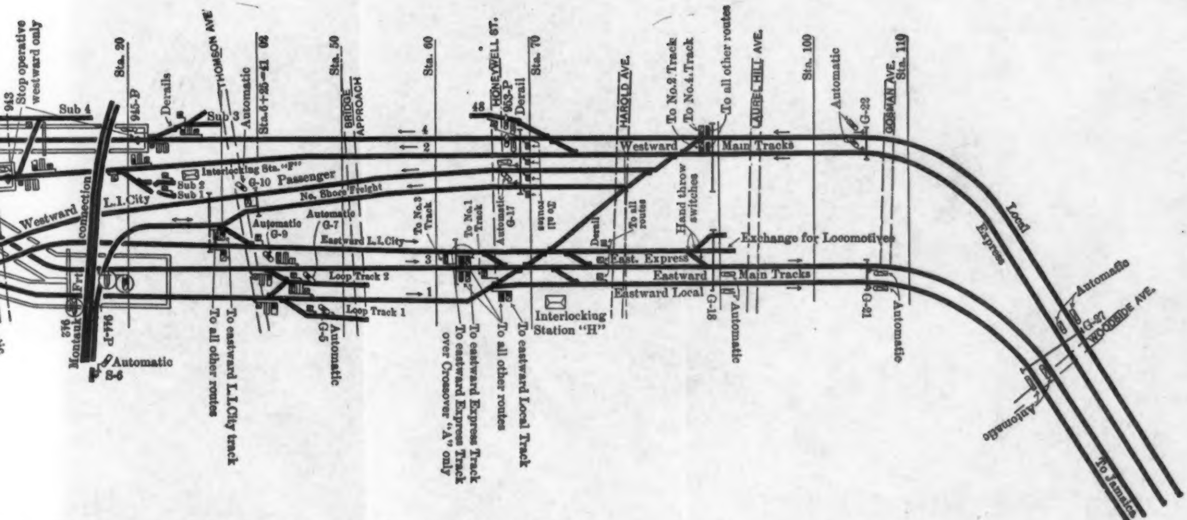


D SIGNALS, TENTH AVENUE TO WOODSIDE.

In addition to the above, secondary circuits are provided for signal control by lever position, by advance signals, by adjacent towers, and by the Train Director through the calling-on arms.

The track circuits are maintained in the rails used for the return current of the traction system, and must, therefore, be of a selective character, operative under all conditions, independent of the presence of the propulsion current. This latter is of the "direct" type, and therefore the signal-control current was made of the "alternating" type, acting upon relays which respond only to this particular kind of current. Continuity of the rail circuit for the propulsion current is maintained at the end of the switch-control sections through copper induction bonds, which allow the heavy propulsion current to pass without material hindrance, and choke back the alternating current sufficiently to maintain the required difference of A. C. potential to operate the signal relays. In the three yards, one rail only is used for the return propulsion current, the other being given up for the signal-control circuits; this is practicable and economical because of the very high carrying capacity of the numerous rails of the parallel tracks, but elsewhere on the main line and in the tunnels, all rails are used for the propulsion return and for the signal operations as well.

Interlocking Machines and Instruments.—All interlocking machines are of the well-known electro-pneumatic type. The control of these machines through the various track and other circuits above mentioned, increases the number of relays much beyond those required by the usual simple interlocking plant, and also requires generally a number of contacts on each relay. Thus, relays are required for: approach locking, and are of the A. C. yard type; an A. C. of the same type of relay for the single-rail track circuits in connection with the locking between cabins and the train-starting system; a D. C. relay, with multiple contacts, for selective and route locking in the cabin machines; a D. C. relay for the light signals; and a D. C. relay for control of the signals through the actual position of the switch points.

A small cabinet is placed over each interlocking machine which, by the presence of a light back of a number, the same as the number of the switch lever, or a number and letter for signal levers, shows when switch levers are unlocked and when signals can be cleared. An electrically-operated track model is also provided. This is a miniature reproduction of the tracks, switches, and signals controlled by the

plant, the switches being automatically moved as the routes are set up, and the occupancy of successive block sections through the tunnels being shown by small lights on the sections of the model. Train describers, consisting of a case with a dial and push button, for announcing departure of trains between cabins; telautographs to transmit special instructions of the Train Dispatcher to towermen; telephone, telegraph, and train-starting system instruments, are all provided in the Station Yard cabins.

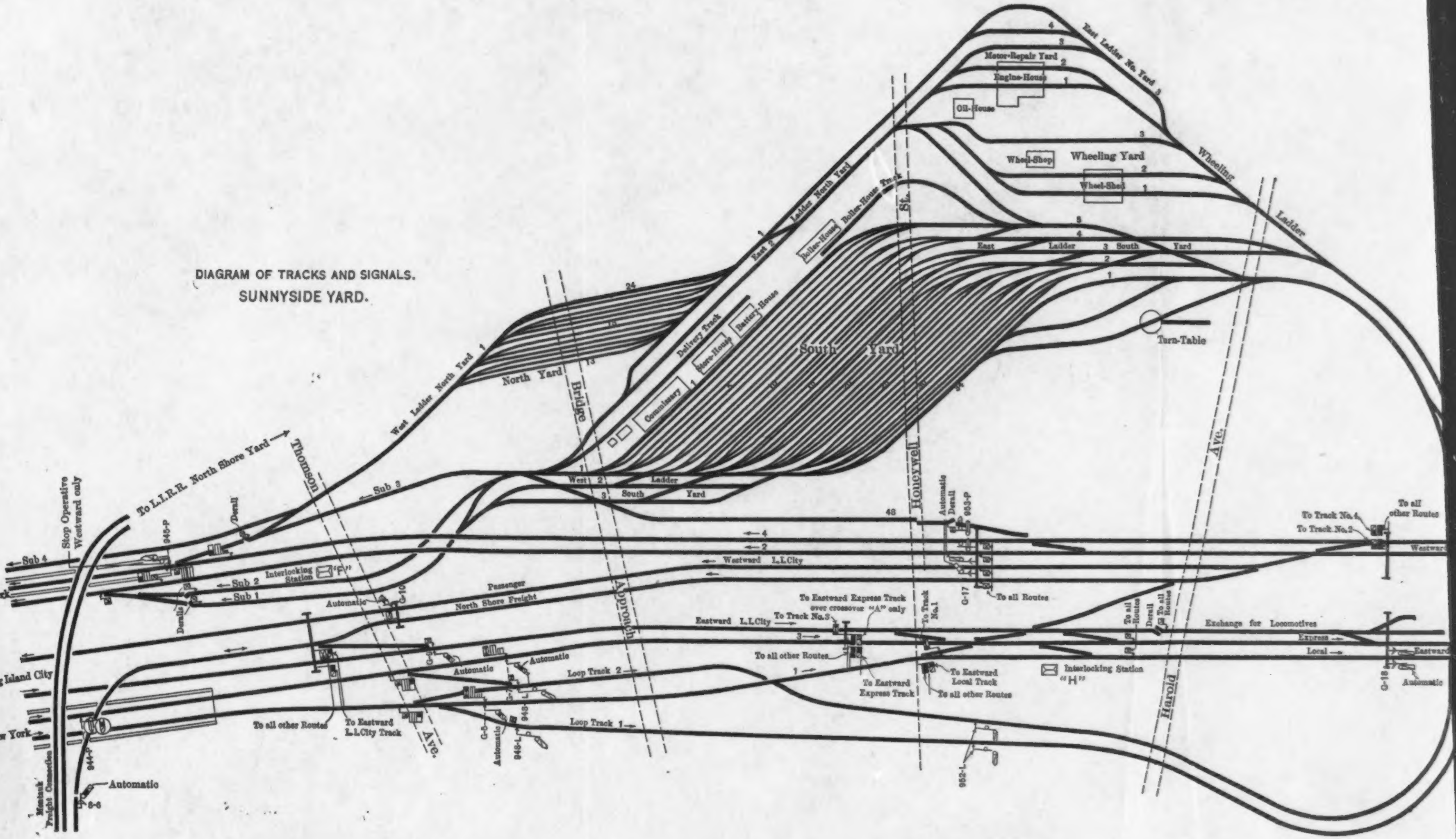
Power.—Compressed air is used for the mechanical operations in the interlocking plants, for the track stops in the tunnels, and for the signals on the Meadows Section. Electric power operates the control circuits for interlockings, track stop control, block signals in the tunnels and yard, and signal lights on the Meadows.

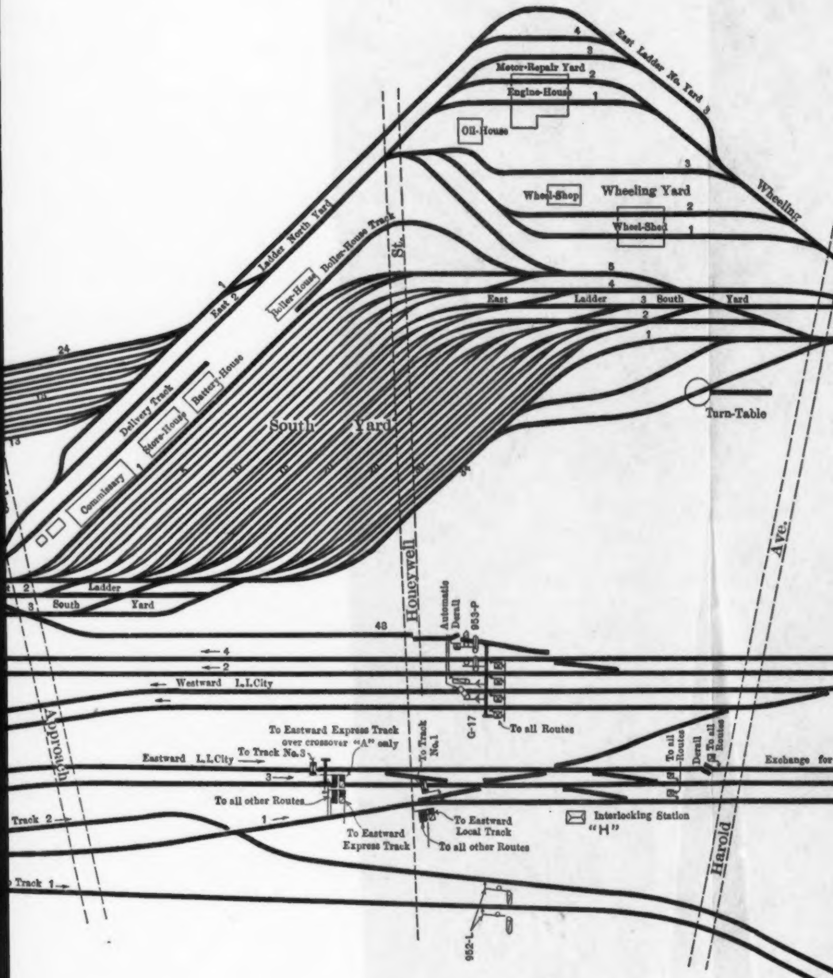
The main air supply is from the 31st Street Service Plant, and is relayed by compressors at Sunnyside Yard and from the New York Division plant at the Meadows Shops.

The piping system consists of duplicate parallel lines in the Station Yard and by a line in each tunnel, with cross-connections for emergency. The pipes are run in the subways under the yard tracks, and at the side of the tunnel benches, and are accessible throughout.

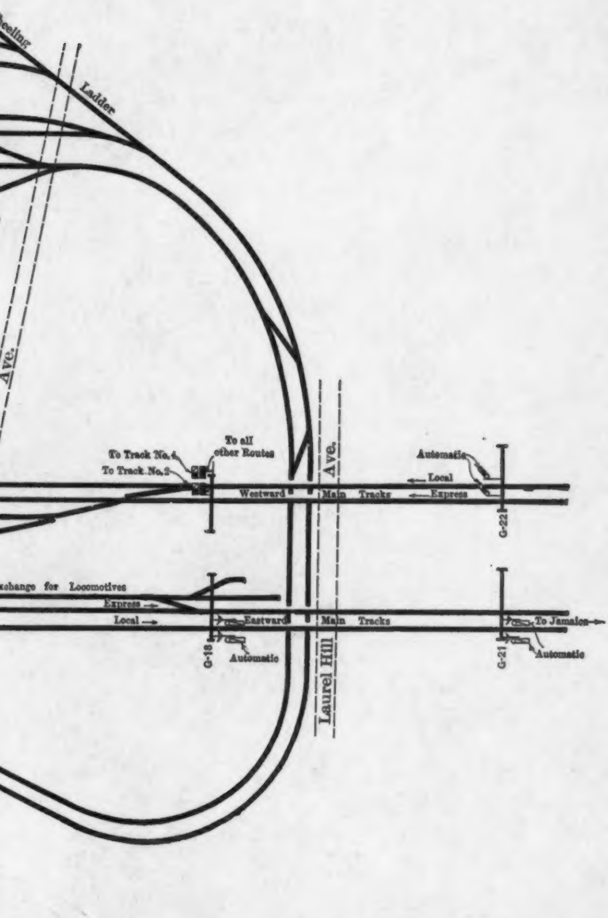
The electric power is from the general auxiliary power system, elsewhere described, the generators, as shown, being relayed at two different power plants. The current is single-phase, 60-cycle, alternating, distributed at 2 200 volts, from a special switch-board in the Service Plant. All mains are in duplicate, and are independent of those used for other purposes. In the yard and tunnels the mains are of rubber-insulated, lead-covered cable, run in a conduit system; on the Meadows and in outlying yards, they are of bare copper, placed on the high-tension power pole line. At the signal cabins and automatic signals, transformers are provided for stepping down the main current from 2 200 to 220 volts for the local systems. This 220-volt current is further stepped down, by special transformers with double secondaries, to 13 volts for the track circuits, and to 55 volts for the signal lamps and other apparatus using A. C. current. In each interlocking cabin, a small motor-generator converts the 220-volt A. C. to 25-volt D. C., to supply the D. C. relays and electro-pneumatic valves. A storage battery, charged by the motor-generators, maintains constancy of the current supply.

DIAGRAM OF TRACKS AND SIGNALS.
SUNNYSIDE YARD.





East Ladder No. Yard
Motor-Repair Yard
Engine-House
Oil-House
Wheeling Yard
Wheel-Shop
Wheel-Shed
Wheeling
Ladder North Yard
East
Boiler-House Track
Boiler-House
Delivery Track
Battery-House
Store-House
Commissary
South Yard
East Ladder South Yard
Turn-Table
Honeywell St.
Harold Ave.
Ladder
South Yard
Automatic Derail
953-P
Westward L.I.City
G-17
To all Routes
To Eastward Express Track over crossover "A" only
Eastward L.I.City
To Track No.3
To Track No.1
To all other Routes
To Eastward Express Track
To Eastward Local Track
To all other Routes
Interlocking Station "H"
To all Routes
Derail
Exchange for
Approach
Track 2
Track 1
952-L


Ladder
Ave.
To all other Routes
To Track No. 4
To Track No. 2
Westward
Main Tracks
Ave.
Automatic
Local
Express
G-22
Express
Local
Eastward
Main Tracks
To Jamaica
G-18
Automatic
Laurel Hill
G-21
Automatic

Manner of Installation.—Because of the complexity of the Station yard track plan, caused by the presence of traction appliances, service piping, etc., the installation of all switch and signal apparatus and circuit work has been made as permanent and accessible as possible. All groundwork foundations are of concrete, and wires are run in fiber conduits set in concrete. The subways under the tracks, and the high station platforms, provided convenient and accessible space for the air-pipe runs, for a large part of the wiring system, and for housing the instruments in their proper locations, so that, while the quantity of apparatus and wiring in the yard is very great, it is felt that all parts of the system can be reached for ready inspection and repairs.

Table 16 is a summary of the various interlocking plants and the movements controlled.

TABLE 16.—CABIN MOVEMENTS.

Symbol.	Location.	Number of Levers:				
		Switches.	Signals.	Traffic.	Spare.	Total.
A	Pennsylvania Station Yard............	68	71	2	38	179
B	" " "	17	13	0	17	47
C	" " "	19	15	2	11	47
D	" " "	23	26	2	20	71
F	Sunnyside Yard......................	11	12	6	18	47
H	" "	14	10	2	21	47
N	Manhattan Transfer..................	28	26	6	11	71
Q	Sunnyside Yard......................	22	18	0	31	71
R	" "	15	15	0	28	59
S	Manhattan Transfer..................	25	23	10	25	83
W	Hackensack River Bridge.............	2	2	5	2	11

The number of relays required for the operation of Cabin "A" is 900, and the total number for all cabins is 2 600. The total length of signal wire used was 1 530 miles.

Organization.

The organization for carrying on the work of the writer's Division was developed primarily for designing and later for construction as well.

Committee Work.—The committees of Pennsylvania Railroad operating officers formed the nucleus for the early and general determinations, and, as the work progressed, passed upon general plans and operating methods, submitted to them by the engineering organization. Thus, at all stages of the work, the general officers of the road were in

touch with the Terminal developments, gave valuable advice, and fixed its operating characteristics. The most important Committees were:

First.—The Yard Committee; determining capacity, train movements, etc., of the Terminal, and developing a track plan;

Second.—A Station Committee, formed to consider the building plans as regards the needed operating facilities, sizes of the different rooms, etc.;

Third.—An Operating Committee, determining tunnel size, signal system, and general operating facilities.

These committees had J. T. Richards, M. Am. Soc. C. E., Chief Engineer of Maintenance of Way, as Chairman, and other important operating officers as members. Subsequently, these three committees were merged into a Joint Operating Committee, with Mr. Richards as Chairman.

Fourth.—A Mechanical and Electrical Advisory Committee, with T. N. Ely, M. Am. Soc. C. E., Chief of Motive Power, as Chairman, formed to pass upon the power-system machinery and other matters of a mechanical nature;

Fifth.—A Locomotive Committee, consisting of the General Superintendents of Motive Power, Lines East and West of Pittsburg, the Mechanical Engineer, and the writer as Chairman; to develop a suitable design of electric locomotive;

Sixth.—A Signal Committee, acting as Sub-Committee of the Operating Committee;

Seventh.—Other special committees, such as for Sunnyside Yard, with Mr. F. L. Sheppard, General Superintendent, as Chairman, to report on particular subjects as occasion required.

In order to present to these committees, from time to time, plans and information regarding the work, the writer was made a member of each.

Division Organization.—The actual work of design and construction was carried out by a Divisional organization, under the Chief Engineer of Electric Traction and Station Construction, who was in executive charge of all work described in this paper, and who reported for approval of plans, for authority to incur expenditures, and to carry out the work, to Samuel Rea, M. Am. Soc. C. E., First Vice-President

of the Pennsylvania Railroad. The work of this department consisted of: 1st, designing, both directly and by supervision of the plans of architects and outside engineers employed by contract; 2d, construction at first hand; and 3d, administration of all construction contracts. The manner of executing only the most important separate sections of the entire work can be referred to here in any detail.

The first is the Station Building. The design of this structure was entrusted to Messrs. McKim, Mead and White, Architects, who co-operated, through the Chief Engineer, with Westinghouse, Church, Kerr and Company, the engineers selected to design the steel framework. The building construction was by the George A. Fuller Company, on a percentage contract, executed through a special field organization of the Architects, under Mr. Daniel T. Webster, an associate member of the firm, acting as General Superintendent. This field organization was sub-divided into Superintending and Inspecting, Time and Material Checking, Auditing, and Contract Divisions. The General Superintendent reported to the Chief Engineer for authority to incur each separate expenditure under the main and sub-contracts of the Fuller Company.

The second section is that of miscellaneous outside engineering and construction. This was entrusted to Westinghouse, Church, Kerr and Company, under percentage contracts, allowing such latitude as seemed fit to the Railroad Company in selecting the best manner of prosecuting the work. Under this arrangement the above organization supplemented the staff of the Chief Engineer in much important engineering work, furnishing the designs for the street bridging and viaducts, the sub-structures in the Station Yard, the machinery for the interior services of the Station Building, and the Main and Service Power-houses, as well as other miscellaneous engineering advice. They, further, executed certain construction work, as from time to time authorized, notably the power-houses and the interior services of the Station. This construction was administered in a similar manner to that of the Station Building, through a field office under George B. Caldwell, M. Am. Soc. C. E., General Superintendent of Westinghouse, Church, Kerr and Company, and reporting to the writer.

The third section covers the designing and construction work done directly by the Chief Engineer's department. This, in general, in-

cluded the determination of plans and reports to the Management, the design and construction of the traction and auxiliary power systems, the installation of machinery in the sub-stations, the Sunnyside Yard and tunnel facilities, and of twenty-eight buildings at various points on the railway; also the laying and ballasting, through the Division Superintendent, of all tracks (except west of the Hackensack Portal), the erection, by contract, of thirty-six buildings, and supervision of the installation of the signal system.

The departmental construction was under the direct charge of Mr. Hugh Pattison, Superintendent of Construction, and his Assistant, Mr. C. G. Edwards, and included the simultaneous prosecution of a great variety of work in the shortest possible time, and in many instances under exceptional difficulties.

The electrical designing work was in charge of Mr. S. A. Spalding, Electrical Engineer; the buildings and structures, Mr. R. D. Coombs, Structural Engineer; and the signal system, Mr. W. N. Spangler, Supervisor of Signals. The inspection of materials and machinery in process of manufacture, and of work under construction, was entrusted to Mr. L. S. Boggs. The trackwork was installed by Mr. C. S. Krick, Superintendent, with his divisional organization under Mr. C. I. Leiper, Division Engineer, and Mr. T. J. Skillman, Supervisor. The general accounting was in charge of Mr. E. J. Bell, Chief Clerk in the Chief Engineer's office. E. R. Hill, M. Am. Soc. C. E., Assistant to the Chief Engineer, was specially charged with the details of the engineering, construction, and inspection work as a whole.

Number of Men Employed.—The following data will perhaps be of interest, in connection with this extensive work:

Average office force employed in designing and supervising work by the Architects', Engineers' and Chief Engineer's offices	272
Average force for inspection of materials	40
Average field force (workmen) for last two years:	
Chief Engineer's organization	1 760
George A. Fuller Company	1 800
Westinghouse, Church, Kerr, and Company	1 100
Other contractors	2 980
Maximum number of men engaged simultaneously on work of this Division	8 529
Average number for the last two years	7 641

CONTRACTS.

The Terminal Division construction, herein described, involved the execution of more than 100 formal contracts for the important separate sections of the work, aside from upwards of 100 000 orders, given in the usual manner, for miscellaneous materials. The contracts were made on forms approved by the Legal Department of the Road. The following contractors supplied important machinery and furnishings:

Arc lights	Adams-Bagnall Company.
Ammonia compressors	York Manufacturing Company.
Air compressors	Ingersoll-Rand Company.
" "	Nordberg Manufacturing Company.
Boilers	Babcock and Wilcox Company.
Brick (courts and driveways)	Harbison-Walker Refractories Company.
" (common and enamel)	Sayre and Fisher.
Centrifugal pumps	Jeanesville Iron Works Company.
" "	Henry R. Worthington.
Cabinet work	Brunswick, Balke, Collender Company.
Cabinet work and interior trim	Sloane and Moller.
Cranes	Northern Engineering Works.
Copper cable (bare)	American Steel and Wire Company.
Column casings (Station Building)	J. B. and J. M. Cornell Company.
Clocks	Self-Winding Clock Company.
Cement	"Atlas," "Alpha," and "Giant."
Electric machinery	Westinghouse Electric and Manufacturing Company.
Economizers	Green Fuel Economizer Company.
Electric switches	A. and J. M. Anderson Manufacturing Company.
Elevators (Station Building)	Otis Elevator Company.
" (Sunnyside Yard)	Albro-Clem Elevator Company.
Electric lights	Nernst Lamp Company.
Escalator	Otis Elevator Company.
Excavation (Terminal Yard, and erection of viaducts)	New York Contracting Company.
Electric light fixtures	Edward F. Caldwell and Company.
Frogs and switches	Pennsylvania Steel Company.
Fire-alarm apparatus	Gamewell Fire Alarm Telegraph Company.
Fire-proofing	National Fireproofing Company.
Garbage destructor	Morse-Bolger Company.

Gate-operating device..........Burdett-Rowntree Manufacturing Company.
Granite ....Norcross Brothers Company.
Glass ....Pittsburg Plate Glass Company.
Inspection: Structural steel......William R. Webster, M. Am. Soc. C. E.
Insulated cable..................Standard Underground Cable Company.
" " ....General Electric Company.
" " ....J. A. Roeblings' Sons Company.
Kalamein wood frames and sash..Sloane and Moller.
" " " " " ..Manhattan Fireproof Door Company.
Kitchen equipment..............Duparquet, Huot and Moneuse.
Locks and hardware.............P. and F. Corbin.
Lifts (baggage and passenger)....Standard Plunger Elevator Company.
Lathing and plastering (Station).H. W. Miller, Inc.
Marble work....................Batterson and Eisle.
Miscellaneous marble............J. H. Shipway and Brother.
" " ....Traitel Marble Company.
Mail-handling machinery........Lamson Consolidated Store Service Company.
Ornamental ironwork (Station)..Hecla Iron Works.
" " " ..Richie, Browne and Donald.
Oil-handling system, Sunnyside Yard ....S. F. Bowser Company, Inc.
Paint (for structural steel)......Toch Brothers.
" " " " ......Detroit Graphite Company.
Plumbing fixtures...............Sanitas Manufacturing Company.
Pumps (Power-houses)..........Epping-Carpenter Company.
" " ....The Heisler Company.
" " ....Henry R. Worthington.
" (Tunnels)..............Union Steam Pump Company.
Paving brick....................C. C. Hendrickson.
Pneumatic tubes................Interstate Pneumatic Tube Company.
Pipe covering...................Keasbey and Mattison Company.
" " ....Johns-Manville Company.
Power-house construction and Station services................Westinghouse, Church, Kerr and Company.
Radiators (Station Building)....American Radiator Company.
Refrigerating machinery.........Brunswick Refrigerating Company.
Refrigerator boxes..............Lorillard Refrigerator Company.

Roofing (skylights)..............National Ventilator Company.
" (Station Building)......J. C. McFarland Company.
Rail (track)....................Bethlehem Steel Company.
" " ....Cambria Steel Company.
Seats (Station Building)........Brunswick, Balke, Collender Company.
Structural steel (Station Building and viaducts)...........American Bridge Company.
Steel poles.....................McClintic-Marshall Construction Company.
Station Building (General contractors) ....George A. Fuller Company.
Signal cables...................Kerite Insulated Wire and Cable Company.
Signals ....The Union Switch and Signal Company.
Safes ....York Safe and Lock Company.
Stack lining....................M. W. Kellogg and Company.
Steel lockers and equipment......Merritt and Company.
" " " " ......Wayne Iron Works.
" " (ticket cases and equipment) ......General Fireproofing Company.
Steel fencing (Sunnyside Yard)..Wayne Iron Works.
Spiral mail chutes..............Otis Elevator Company.
Third-rail ....Cambria Steel Company.
Telephone cables................The Waterbury Company.
" " ....Western Electric Company.
Telautographs ....Gray Telautograph Company.
Train indicators................National Indicator Company.
Tower foundations (Hackensack River transmission crossing).F. M. Stillman and Company.
Turbines ....Westinghouse Machine Company.
Umbrella sheds (Sunnyside Yard) Brann and Stuart.
Ventilating fans (for tunnels)...American Blower Company.
" " (station heating) B. F. Sturtevant Company.
Vault lights....................Tucker and Vinton.
Vaults ....York Lock and Safe Company.
Valves ....Chapman Valve Company.
" ....Nelson Valve Company.
Water filters...................Loomis-Manning Company.
Yard Buildings (blower-houses and signal cabins)...........John W. Ferguson Company.

Conclusion.—The writer, in concluding this lengthy, but inadequate, description of a portion of this great terminal construction, desires

to express his obligations to very many persons, the officials of the Pennsylvania Railroad Company, his staff, and many others. He feels unable to do this adequately, but the following names should be specially mentioned: The late Mr. A. J. Cassatt, President, to whose extraordinary foresight and grasp of detail is due the Tunnel Extension and Station as an accomplished fact, substantially in detail as he had approved it years before its construction; Mr. Samuel Rea, First Vice-President, the Executive in direct charge of the entire project for which he had labored for so many years, and to whom the writer feels under special obligations for support and confidence in his efforts; A. J. County, Assoc. Am. Soc. C. E., in discharging his varied duties as Assistant to the First Vice-President in connection with the work; the Directors of the Company, and its President, Mr. James McCrea, who continued and financed the great work; and to the other Executives, who take possession of the completed project and assume the responsibility of making it a commercial success in its operating and traffic relations. The writer is also indebted to the members of the Pennsylvania Railroad Committees, for valuable assistance, among whom are:

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AMERICAN SOCIETY OF CIVIL ENGINEERS
INSTITUTED 1852

TRANSACTIONS

Paper No. 1166

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

DISCUSSION ON THE SIXTEEN PAPERS DESCRIPTIVE OF THIS WORK (NOS. 1150 TO 1165), ALL OF WHICH ARE CONTAINED IN VOLUMES LXVIII AND LXIX.

BY MESSRS. EDWARD WEGMANN, CHARLES E. FRASER, HENRY JAPP, A. BARTOCCINI, C. L. HARRISON, J. V. DAVIES, WILLIAM J. WILGUS, CHARLES S. CHURCHILL, G. R. HENDERSON, EDWIN B. KATTE, GEORGE A. HARWOOD, N. W. STORER, J. H. GANDOLFO, E. R. HILL, AND GEORGE GIBBS.

Mr. Wegmann. EDWARD WEGMANN, M. AM. SOC. C. E.—The authors have given a very interesting account of the construction of the Pennsylvania Railroad Tunnel across Manhattan Island, with details of the methods adopted and the difficulties encountered.

In 1886-1891, the speaker had charge of the construction of a tunnel on Manhattan Island for the New Croton Aqueduct. Compared with the Pennsylvania Railroad Tunnel, it was a small affair, the diameter of the excavation being only 15 ft. 7 in. Its direction was at right angles to that of the Pennsylvania Railroad Tunnel, and nearly parallel with the strike of the rock, and, as some of the details may still be of interest, they will be briefly described.

The Aqueduct Tunnel was driven in rock from 80 to 170 ft. below Amsterdam and Convent Avenues, from 135th to 179th Streets. The excavation was circular, and generally 15 ft. 7 in. in diameter. The Aqueduct built in this tunnel had an interior diameter of 12 ft. 3 in., and was lined with 16 in. of brickwork and then with rubble masonry to the sides of the excavation.

Mr. Wegmann.

Six shafts, 8 by 17½ ft. in section, in the clear of the timber, and from 1 400 to 2 700 ft. apart, were sunk to expedite the driving of the tunnel. Three of the shafts were located in the center of Convent Avenue and the remaining three in Amsterdam Avenue. The tunnels excavated under the avenues mentioned were joined by a reverse curve of 350 ft. radius.

At the bottom of each shaft, top-headings, about 7 ft. high, were driven, and the excavation of the bench followed closely, being kept generally within from 50 to 75 ft. of the face of the heading. From eighteen to twenty holes were usually drilled for the heading, and from four to six for the bench. The amount of drilling for all of these heading and bench holes was ordinarily about 180 lin. ft. Occasionally, three horizontal lifting holes were drilled for the bench near the bottom of the tunnel.

Atlas powder, forcite powder, dynamite, etc., were the explosives generally used, the different grades containing from 40 to 75% of nitro-glycerine. A powder having 60% of nitro-glycerine was placed in the eight center-cut holes, while a 40% grade was found sufficiently strong for the remaining holes. Allowing for block holes and wastage, about 100 lb. of powder, half with 60% and half with 40% nitro-glycerine, were required to fire one set of heading and bench holes, which, according to the hardness of the rock, advanced the tunnel from 3 to 6 ft. The weekly progress of the different headings varied from 15 to 50 ft.

The only bad piece of ground was encountered about 400 ft. south of 149th Street. A soft seam of slippery material (talc, clay, and decomposed rock), about 12 in. wide, was uncovered on the west side of the tunnel. The contractors were ordered to timber the excavation at this point, but as they delayed executing this order, a considerable quantity of soft material from the seam slid into the tunnel and caused a general cave-in.

The work was stopped for about a month, and then the heading was excavated through the mass of loose rock that filled the tunnel by using "crown-bars." A small drift, about 3 ft. wide and 4½ ft. high, reaching 2 ft. above the space required for the brick lining, was made on the center line of the heading. A heavy crown-bar or log, about 12 in. in diameter and from 15 to 20 ft. long, was placed in this drift and supported by vertical props from the floor. Four more bars —two on each side of the central log—were placed in the loose rock in like manner. The top lagging of the small drifts was blocked up from the bars, and, in this way, a roof of crown-bars, properly lagged, was formed above the space required for the masonry arch.

The excavation of the bench was then commenced. As the rock was removed by light blasts, strong frames of 12 by 12-in. hemlock timbers were erected to support the bars. Smaller logs were placed

Mr. Wegmann. on top of the caps between the principal bars, in order to prevent any stones from falling. The principal bars were not moved forward as the heading progressed, as is usually done in this method of tunneling, but were left in place, new bars being used.

The principal soft seam crossed the axis of the tunnel at an angle of about 6°, so that the bad ground changed from the west to the east side of the tunnel in a distance of about 150 ft. Besides the principal soft seam, there were very thin layers of soft, slippery material between the hard strata, which tended to produce slips.

The original fall extended for about 30 ft. The loose rock above the bars was removed as much as possible and replaced by small logs. After the bad spot had been passed, the rock was excavated by light blasting about 10 ft. in front of the timbering, which was continued, but without crown-bars, as the heading advanced.

The conduit, to be built in the tunnel just described, was to be under pressure. If not confined, the water would have risen 37 ft. above the surface of the ground (or 60 ft. above the tunnel). To avoid damages which might be caused by the water escaping from the tunnel, it was decided to line the aqueduct at this bad place, with an iron lining for a distance of 234 lin. ft.

The iron lining consisted of hub and spigot rings put together in ten segments, the upper ones being made shorter than the others to facilitate putting them in place. The longitudinal joints of the ironwork were made with lead gaskets and with a rust-joint filling (iron shavings mixed with sal-ammoniac and water), but the circumferential joints were only filled with Portland cement. The iron lining was backed with 18 in. of brickwork and then with rubble to the sides of the excavation. Where possible, the timbers were removed, but a great many had to be left embedded in the masonry.

The removal of the main timbers, as the iron rings were erected, was a very hazardous operation. Toward the end of the lining the contractors removed the timbers too far in advance of the completed aqueduct. This caused a second fall of rock, which, fortunately, was much less in extent than the original one.

Allusion is made to difficulties encountered in constructing tunnels on Manhattan Island where watercourses existed before the surface was changed by excavation and filling in. The topographical map prepared by General Vielé is a good guide in finding such places.

The speaker found some of these watercourses when building foundations for the New York Elevated Railroads. On Second Avenue the foundations on the east side were on hard clay, while 24 ft. to the west an old stream bed was encountered, which necessitated the driving of piles from 30 to 40 ft.

In building the Centre Street Loop of the Subway Railroad of New York, near the Tombs, soft bottom was found, which obliged the engi-

neers to resort to pile-driving in order to obtain a good foundation. Many are probably unaware of the fact that where the Tombs and the surrounding buildings stand, there was formerly a pond, 50 ft. deep, known as the Collect Pond. It was on this pond that Fulton made his first experiments in steam navigation, and here is where New York City obtained its first public water supply, by pumping the water from the pond to a reservoir built on the east side of Broadway at Franklin Street. Mr. Wegmann.

Charles E. Fraser, M. Am. Soc. C. E.—The authors of the papers on the East River Tunnels are to be congratulated on the very interesting and graphic description they have prepared of a great engineering achievement. All who were engaged on the work will value these papers as a record of five years of interesting labor. Mr. Fraser.

In connection with the sinking of the north caisson at Manhattan, it was necessary to underpin the three-story brick building fronting on East 34th Street, the foundations of which came within 18 in. of the line of the caisson. The building stood on filled ground, the walls being directly on the ground, without piles or sills of any kind. The task was to carry its foundations to solid rock, about 26 ft. below the footings and some 26 ft. below mean high tide. As the building was not heavy, it was decided to attempt to execute the work without the use of compressed-air caissons, and this was successfully accomplished. After the building had been properly braced and needled in the usual manner, pits were sunk, one at a time, beneath the walls adjacent to the position of the large caisson. It was found that the fill included some old wooden cribs, and that it was possible to select one pocket of a crib for each pit, thus saving timbering and making it possible to sink the pit very rapidly. The crib extended to within about 7 ft. of the rock and rested on compressed silt and boulders. At the bottom of the crib 2-in. sheeting was started, and driven down as the excavation progressed. The work proceeded so rapidly that concrete piers were erected in each pit before lost-ground settlements could work up to the footings of the building.

The time record made in sinking the north caisson at Manhattan (without the use of compressed air) is worthy of mention. The caisson was started about May 1st, and was sunk to a depth of approximately 50 ft. The caisson was then stopped, and excavation was continued in the solid rock to a total depth of about 90 ft. Four tunnels were then driven, two westward and two eastward, the westward tunnels extending 200 ft., and the eastward tunnels as far as the rock was considered safe. The shaft was timbered below the bottom of the caisson. The shields were then erected in the bottom of the shaft and pushed into the eastward tunnels. Concrete bulkheads with air-locks were built at once behind the shields, and the driving of the shields under air pressure was begun. This work, from the starting of the

Mr. Fraser. caisson to the starting of the shields under compressed air, occupied less than 7 months.

A study of Table 2, in the paper by Messrs. Brace, Mason and Woodard, will show that the four Manhattan shields were started at very short intervals during the fall of 1905. Owing to shortage of air, however, it was found necessary to shut down two of the tunnels, namely, *A* and *C*. The driving of Tunnels *B* and *D* was continued. The working of these faces was attended with many difficulties; the problems of driving them, however, were solved in so far that the shields in Tunnels *A* and *C*, after being shut down for many months, almost overtook those in Tunnels *B* and *D*, before the meeting place under the river was reached. Tunnel *A* was shut down for practically 10 months, and covered the distance to the east side of Blackwell's Island Reef in about 8 months' less time than Tunnel *D*, which had been driven continuously during 27 months.

Those who did not see the shields can hardly conceive how strong they were. E. W. Moir, M. Am. Soc. C. E., who designed them, seems to have worked on the principle that nothing could be too good, or too strong, or too completely equipped to start out under the river. Each of the Manhattan shields was driven through some 1 200 ft. of tunnel where the face was all or partly in rock. This necessitated a large amount of blasting directly in front of the shield, and tunnel men will understand the nature of the punishment it endured whenever rock was blasted. Hundreds of cuts were fired directly in front of the shield, and not more than 3 ft. distant from it, yet there were practically no repairs to the shields, and, at the conclusion of the work, they could have been driven as far again, had the tunnels been that much longer.

As to the speeds made in driving the shields, it is very difficult to make fair comparisons in tunnel work. The ground varies so much, even in the same neighborhood, that it is hard to make a rule as to what might be fair progress under any given condition. At Manhattan, when the work was fairly well organized, it was found that $2\frac{1}{2}$ ft. per day of driving was as much as could be accomplished in solid rock. This might have been improved had the all-rock sections been longer. In solid-rock tunneling, of course, the shield is decidedly a detriment to speedy driving. In a mixed face, that is, rock bottom with soft ground in the upper part of the face, a speed of $3\frac{1}{2}$ ft. per day was considered very good. In the soft ground—fine sand with a few very thin layers of clay—the best speed made on the Manhattan side was 32 rings, or 80 lin. ft., of tunnel per week. This record was beaten by three rings in the Long Island tunnels, where the soft-ground tunneling did not begin until 3 months after all soft-ground tunneling at Manhattan had been completed. Regarding the mixed face it might be remarked in passing that the best speed was made when the rock extended up

Mr. Fraser.

about 8 ft. above the invert. It was found that a heading right down in the bottom was not as good as one 3 or 4 ft. higher. So many schemes for handling mixed faces were tried, that it is impossible to discuss all of them at this time. It was even attempted to drive a soft heading in advance of the shield out on top of the rock, the idea being that the rock bench could then be drilled in advance of the shield. It developed that this left the soft ground in a disturbed condition for too long a period before the shield was driven into it, greatly increasing the escape of air through the soft material. It is a question whether any heading at all is advisable in shield tunneling, except where there is a full face of rock and the rock cover ahead of the shield is known to extend for a considerable distance. During the latter part of the mixed tunneling from Manhattan, headings were abandoned altogether, and all the shooting was done directly in front of the shields. In this method the cuts were drilled low down by machines mounted in the side pockets in the bottom of the shield. Side rounds were drilled by machines mounted on the middle-floor pockets of the shield. This method entailed very heavy shooting directly in front of the shield, but the shields were strong enough to stand that treatment.

Mr. Japp.

HENRY JAPP, M. AM. SOC. C. E.—The five years, stated by the authors as required for the completion of the East River Tunnels, included the time of waiting for the erection of the first caisson, which was not ready for lowering until April, 1905, or nearly one year later than the date given for commencement.

The segmental plates, which projected 5 in. beyond the outside of the tunnel lining near the Manhattan shafts, had a very important duty to perform, as they had to prevent the short length of tube already built, together with the air-locks, from being pushed backward into the shaft by the air pressure on the bulkhead and the pressure of the shield jacks, a possible load of more than 10 000 000 lb. Such a contingency seldom arises, but here the temporary tunnel lining built across the shaft to take this thrust had to be removed to make room for the contractors for the Crosstown Tunnel.

The shutters, which would have been useful if the material had flowed against them, were unsatisfactory when it stood up several feet clear of them, the miner's motto, "Hold what you get," being only attainable in material of this class by close poling. Time was lost in the Long Island City shields in soft ground owing to the desire of the superintendents and men to get a shove before sufficient material was excavated and before what was excavated was properly supported. This damaged the hoods, and caused the face to break up and become very wet ahead of the work, and, running below the axis of the shield, it required an increase in the air pressure which could have been avoided by holding the face.

Mr. Japp. The shutters were very effective in reducing air leakage. On one occasion they were pugged so tightly that the difference in air pressure between the tunnel and the outside of the shutters was sufficient to break by tension one of the screws, 2 in. in diameter, which held the shutter, and the out-rush of air carried the heavy steel shutter out beyond the shield. Sudden blows were so powerful that in one case an able-bodied man was thrown off his feet by the rush of air, and sometimes, for brief intervals, it was impossible to make one's way out of the shield through the doors against the in-rush of air.

When Tunnel *B* passed beyond the Manhattan ferry slip bridge, it blew out with such force that mud was thrown over the upper cross-girder of the bridge, 40 ft. above the water level, and one large niggerhead was thrown out of the water and landed on the bridge, breaking the decking.

In all cases the alignment of the work was remarkable, when one considers that the lines had to be passed down through the air-tight floors of the caissons and transferred through the bulkheads in the tunnel. The final result, namely, that the concrete-lined tubes for 24 000 lin. ft. are within $\frac{3}{8}$ in. of the line and grade shown on the original contract drawings, is the most wonderful achievement in alignment that the speaker has known, and the authors should be very proud of it.

In the speaker's opinion, the safe working capacity of the compressor plant, stated by the authors to be 20 000 cu. ft. per min., will not be accepted by the makers of the plant. Corliss engines as large as these compressors run continuously at 100 rev. per min.

The recorded maximum of 33 400 cu. ft. for the Long Island tunnels, taken from the 24-hour records of the revolution counters, does not give the maximum for brief periods. The speaker has seen all the air compressors in the Long Island City power-house operating on four tunnels, each compressor running at its full capacity or more, and giving a maximum of at least 45 000 cu. ft. per min.

The clay blanket was very successful; only one tunnel, namely, Tunnel *D*, Manhattan, was flooded, and that occurred two days after the permit was obtained from the War Department to raise the blanket to the required level, or before the clay could be obtained, and, unfortunately, two men were drowned, the only two lost in that way. On that occasion the water rose a little above the bottom of the safety screen on the back of the shield and within 14 in. of the underside of the nearest safety curtain in the tunnel.

Although the clay blanket was undoubtedly a necessity, the speaker does not think that it alone would have mastered the difficulties. During severe blows, as many as three scows, each containing 600 cu. yd. of clay, have been dumped one after the other as quickly as possible, over the blow, only to be tossed to one side by the escaping

air. The dumping often had little effect until the outside of the tunnel lining was grouted up to within a few inches of the roof, confining the escape of air to narrow margins, and until the top had been filled up with blue Lias lime which had the property of setting quickly. Much of this lime was carried upward by the escape of air, adhered to the fissures in the sand, and choked off the escape. Mr. Japp.

It was often difficult to find the point of escape; sometimes it was as many as ten rings back of the tail of the shield, and sometimes it was directly over the shield, but very seldom in front of it. Air escaping through the breasting generally made its way backward over the roof to an opening in the ground which had settled over the shield or tunnel. In some beds of open material the air undoubtedly blew straight through the face. In that case dry lime thrown against the face and sucked into the interstices of the open material was generally effective.

With regard to the difficulty of building the ring with the erector when the shield was shoved too far, or when it was pitched on a stiff lead, each erector was fitted with an adjustment to take care of this, but it was required so seldom that it was often forgotten by the men doing the work.

The broken plates in the invert of the tunnel were very puzzling, and it seems to the speaker that so long as it is necessary to break joint with segments which have been machined none too accurately as regards width, this trouble will always exist in material where the shield requires a high pressure for shoving. The bead within the tail is sometimes criticized, but the only objection to it that the speaker can see is the possibility of a wrench being dragged along by the bead under the iron. Its advantages are that it helps to tie the tail plates of the shield together and prevents their splitting and crumpling when sudden changes of lead take place; it also insures that the iron will always be clear of the tail of the shield at the point where the new ring is to be built, except where excessive leads are adopted, and then tapered rings are necessary.

Great care was taken to prevent the Portland cement grout from freezing the shield to the lining or to the rock. This took place only once (in Tunnel *D*, Long Island City), and then there were some anxious moments as the hydraulic pressure was gradually raised to its maximum before the shield was liberated. The danger of lumps of cement grout sticking to the outside of the shield and acting as plows in the soft material, thus preventing the driving of the shield on the required alignment, is also a point worth considering.

The method adopted by the authors in closing off the leaks which appeared in the concrete lining due to shrinkage was very ingenious and successful.

Owing to the difficulties of making rust joints, it looked as though

Mr. Japp. the flanges of the iron were slightly bent in bolting up, and the slackening of a bolt was sufficient to cause the iron to spring away from the hardened rust caulking and permit a leak.

In the speaker's opinion the difficulties of broken plates and water-tightness would be avoided to a large extent, if mild-steel tunnel lining could be used instead of cast iron.

The speaker wishes to congratulate Messrs. Brace, Mason, and Woodard on this excellent paper and its valuable illustrations.

Mr. Bartoccini. A. Bartoccini, Assoc. M. Am. Soc. C. E. (by letter).—In his description of the work on the Long Island Approaches to the East River Tunnels, Mr. Clarke states that the heavy wall built between the two tracks, in the invert approach to *B* and *D* Tunnels, was adopted for the purpose of holding the structure down against the upward pressure of the mud. According to the plans and cross-sections, the entire invert is built on piles. Piles, as a rule, are brought into action for the purpose of supporting a load and keeping the structure from sinking; consequently, it seems that either the piles or the heavy wall separating the two tracks are superfluous. In case the preference was to use piles, and the structure had a tendency to rise because of the upward pressure of the mud, the iron reinforcing the concrete might have been made fast in some way to the heads of the piles, and, in this case, instead of playing the part of bearing members, they would have served as anchors.

The difficulty caused by the presence of the water-proofing might have been eliminated simply by doing away with it, as a mass of concrete varying in thickness from 10 ft. to nearly 4 ft., may be considered practically impervious to a low head of water, especially if the concrete is mixed and laid properly.

Furthermore, by examining Section *L-L* at Station 27 + 50 (*B*), in Plate XXVII, it is seen that there is a distance of 25 ft. $3\frac{3}{4}$ in. between the centers of the tracks. Had this distance been made 12 ft., as in many electrified roads, the width of the structure would have been reduced by 13 ft. $3\frac{3}{4}$ in. Assuming the head of liquid mud above the water-proofing to be 18 ft., and the minimum weight of the liquid mud to be 100 lb. per cu. ft., the upward pressure per linear foot of structure caused by its extra width of 13 ft. $3\frac{3}{4}$ in. amounts to 23 900 lb.

Allowing the concrete a weight of 150 lb. per cu. ft., the wall being 6 ft. wide at the top, 8 ft. at the bottom, and 17 ft. high, and taking a section of floor 13 ft. $3\frac{3}{4}$ in. wide and 3 ft. high, the weight of the middle wall and section of floor from the water-proofing up, for the corresponding linear foot of structure, would be 23 850 lb. The weight of the added wall and floor, therefore, is almost exactly balanced by the extra upward thrust due to the increased width of the structure necessary to accommodate this wall.

C. L. HARRISON, M. AM. SOC. C. E. (by letter).—In laying out the plan for presenting to the Society the papers for the East River Division, the closing discussion was assigned to the writer. Mr. Harrison.

The only questions raised which seem to require a reply are those by Mr. Bartoccini in regard to the design of the approach to Tunnels *B* and *D*, he expressing the opinion that either the piles or the middle wall between the two tracks is unnecessary, and suggesting means of dispensing with the latter.

In considering this design, it must be remembered, that the approach was located in an old swamp, the soil of which could be displaced by the slightest additional weight, and that the ground-water level varied from 1 to 3.5 ft. above mean high tide. In the design, the bearing power of the soil was neglected, and the lifting force of the ground-water was taken as equal to the hydrostatic head above the water-proofing acting uniformly over the base, the water weighing 64 lb. per cu. ft.

Calling the width of the invert a, and the head h, then the lifting force on 1 lin. ft. of invert $= 64\ h\ a = H$.

Likewise, call the weight of concrete for 1 lin. ft. of invert W_c;
the weight of back-fill on steps for 1 lin. ft. of invert W_b;
the weight of track for 1 lin. ft. of invert W_t;
the live load for 1 lin. ft. of invert W_l.

First consider the necessity of piles for supporting the invert. The load which they are required to carry varies under different conditions, and, for clearness, will be discussed under operating conditions and under conditions during construction, the latter period being considered as ended previous to the laying of the track.

Let the load on the piles for 1 lin. ft. of invert during traffic $= L_t$; and the load on the piles for 1 lin. ft. of invert during construction $= L_c$.

Then will $L_t = W_c + W_b + W_t + W_l - H$.............(1)

With H a maximum, L_t is probably small; but the live load, W_l, becomes 0 between trains, and L_t must never be less than 0 or the structure would rise; therefore,

$W_c + W_b + W_t$ must be $> H$.........................(2)

and $L_t > W_l$...(3)

Or, stated in words, the piles must always carry the live load and in addition thereto that portion of the weight of the structure which forms the margin of safety against rising.

Now, as h decreases, H will likewise decrease, and L_t will increase.

Suppose that some future construction in the immediate vicinity should cause the ground-water to be pumped down to the level of the water-proofing; then h and likewise H will become 0, and, from Equation 1:

$L_t = W_c + W_b + W_t + W_l$..........................(4)

Mr. Harrison.

Now consider the loading during construction:

$$L_c = W_c + W_b - H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

All the terms of Equation 5 will necessarily vary during construction.

The ground-water was of necessity kept below the level at which work was being done, and as the construction was built in 50-ft. sections, and the water-proofing was frequently not laid until the next adjoining section, or the next section but one, was completed, h, and therefore H, was zero for the completed section; and, from Equation 5,

$$L_c = W_c + W_b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

This is a very appreciable loading, and one which was actually carried during construction, but, as it is somewhat lighter than the loading called for by Equation 4, the latter was used in designing the piles. Surely Equations 4 and 6 justify their use.

Now, as to the necessity for the middle wall, or some other device for holding the invert down; this will be discussed, as were the piles, for both operating and construction conditions.

Take Equation 2, and when H is a maximum there is a condition which requires the middle wall, although a slightly lighter wall than that built would have satisfied that condition. Using Equation 5, and assuming that H would become a maximum before the tracks were laid (which in fact it did), then, as L_c must not be less than 0 or the structure would rise, we have:

$$W_c + W_b > H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Equation 7 requires the middle wall to be heavier during construction than under operating conditions by an amount equal to the weight of the tracks, and shows the conditions for which it was designed.

Mr. Bartoccini states that two other methods of meeting the conditions could have been used more economically:

First.—By anchoring the invert to the piles, and thus introducing an additional positive factor in the first term of Equation 7;

Second.—By reducing the width between tracks to 12 ft., and thereby reducing the value of H sufficiently to make the equation true without the weight of the middle wall.

If we grant the possibility of attaching the reinforcing steel to the heads of the piles with sufficient strength to withstand the maximum lifting pressure, and at a cost less than that of the concrete in the middle wall, the structure would then rise when H is a maximum by lifting the piles, because many of them are only from 6 to 10 ft. long, and are in very soft material, supporting the structure from the rock as short columns and not by friction.

If the piles were sufficiently long to form anchorage for the structure, this would, as Mr. Bartoccini says, destroy the efficiency of the

Mr. Harrison.

water-proofing which he considers unnecessary. It is quite possible that the hydrostatic head is not sufficient to force any appreciable quantity of water through 4 ft. of well-laid concrete, but Mr. Bartoccini neglects the fact that the structure was of necessity built in sections, having a joint every 50 ft., and that it is subject to great changes of temperature, which would undoubtedly open the joints sufficiently to admit large volumes of water. The first method, therefore, would be unsatisfactory for two reasons, either of which is sufficient.

In the second method suggested, he assumes that the only reason for having the tracks more than 12 ft. between centers was to accommodate the middle wall, when, as a matter of fact, the wall had absolutely nothing to do with the spacing of the tracks; their distance apart being fixed at the tunnel portals, 33 ft. west of the section selected by Mr. Bartoccini, by the design of the tunnels, and decreased eastward as rapidly as possible without spoiling a very good alignment.

The distance apart of the tracks at the portals is 25 ft. 7¼ in., and it would be possible to reduce that width by 4 ft. and still have the tracks in separate tubes; but that additional width, the elimination of which would not have allowed the middle wall to be dispensed with, or even greatly reduced, was required for a cable tower, as shown on Plate XXVI.

It must be remembered that, as mentioned in the first paper of this series* by General C. W. Raymond, M. Am. Soc. C. E., two of the essential features of the design of these tunnels were the construction of each track in a separate tube and the provision of the benches on either side of each tunnel. The single-track tubes were adopted in order to prevent the possibility of a derailed train wrecking another coming in the opposite direction, and likewise to insure perfect ventilation; the two benches were to provide, on one side, room for signals and a convenient place for inspectors and repair men to work on them, and, on the other, a clear walk on which passengers could make an exit from the tunnels in case trains were stalled or derailed. Those features, essential to the safety and comfort of the passengers, were insisted on by the Management, and would not have been abandoned on any such ground as economy. The day has gone by for sacrificing safety to economy.

As the discussions have been very few, it might be well to mention some of the the lessons learned in building the tunnels under the East River, as these presented the most difficult and interesting problems. These difficulties would have been much less in a tunnel of small diameter, especially through a section which was all sand, or part sand and part rock.

The outside diameter of the iron lining was 23 ft., which gave a

* *Transactions*, Am. Soc. C. E., Vol. LXVIII.

Mr. Harrison. hydrostatic pressure more than 10 lb. greater at the bottom than at the top of the working face. If air pressures could have been maintained, which would have kept the bottom of the working faces dry, the most serious difficulties in driving the tunnels would have been eliminated at once; but this would have given a pressure at the top of the working face of more than 10 lb. in excess of the hydrostatic pressure, would have increased the escape of air through the overlying materials, and would have resulted in "blows." Probably this escape of air could have been greatly reduced if the tunnels had been deeper in the ground, but in order to secure satisfactory grades, it was necessary to build them as near the river bottom as safety in doing the work would permit. The use of the temporary clay blanket on the bed of the river made it possible to drive them higher than could have otherwise been done. In doing the work it was found that if the air pressure balanced the hydrostatic pressure at the bottom of the tunnel, the chance of "blows" was too great, and if this balance was had at the top, the inflow of sand and water was too great. Generally it was found best to carry the balance at about the horizontal diameter of the tunnel, which resulted in the material being wet and soft at the bottom and dry at the top. In localities where the material contained strata of clay, the air pressure was raised higher, resulting in greater speed and ease of working.

Notwithstanding the extensive use of the clay blanket, there was a large escape of air through the overlying sands, which was a source of much anxiety to every one connected with the work. Several methods were tried to prevent this. Breast-boards plastered with clay were of material benefit. Grout was used extensively in the face in an effort to consolidate the material. In digging out the sand into which the grout had been injected under pressure, it was found to be collected in masses and not generally distributed; this was true whether the sand contained a large or a small percentage of voids. The interstices between the grains of sand were too small to permit the free flow of grout into them; however, grouting in the face did compact the material to some extent and reduce the flow of air through it. It was also found important to keep the grouting outside the iron lining and close to the shield, thus reducing the area of the surface through which the air might escape. These measures were taken to prevent blows, but it was often found very difficult to stop them after they had once started. For this purpose, bales of hay, bags of sawdust, sand, and clay, were stored in the tunnel near the shield for ready use. In the early stages of the work large quantities of grout were also injected into the blows. For this purpose Portland cement was tried, but it was of little benefit on account of the time required for setting. Blue Lias lime, which had been used extensively in England, was also tried. This lime set in air in from 10 to 15 min. and

was about as hard as chalk. Its use was advocated on account of its property of swelling. It is found that when mixed neat it has from 50 to 100% greater volume (depending on the quantity of water used) when set, than in its dry state. This swelling, however, takes place in the mixing pan and cannot be of much help in compacting the material into which it is injected. A similar lime made in the United States was also tried, as well as some specially manufactured quick-setting natural cements. None of these grouts seemed to be of material benefit in stopping blows when injected into them. Probably the most effective treatment of a blow was to dump clay on it, and a dump scow was usually kept on hand, loaded, for such an emergency. To place the scow accurately over the boiling water was difficult, but when a pocket was dumped in the right place, the blow was reduced or stopped. Mr. Harrison.

When driving through soft material and using an air pressure about equal to the hydrostatic pressure at the horizontal diameter of the tunnel, there is an upward pressure on the bottom of the iron lining as it leaves the shield, and a variable downward pressure on the top due to the materials settling. Below the water line the soft material flows into the space left by the shell of the shield as it is moved forward; above the water line the material is stiffer and does not flow. This results in a cavity on each side near the horizontal diameter and if not prevented the tube will flatten. Therefore, tie-rods with turn-buckles should be put in at the horizontal diameter immediately after the iron leaves the tail of the shield. A traveling platform following the shield is very useful in furnishing space for storing materials, tools, etc., needed in the work. The track for this platform should be high enough not to interfere with placing the tie-rods.

It is important to have the tail of the shield of such length that when it is shoved forward to erect a ring of iron, the ring previously erected will be wholly within the shield, so that any broken or damaged segment can be removed and replaced without danger of the sand flowing in. Great care should be taken to have the face of the iron free from sand or other materials so that the iron will fit face to face and admit of the face of the new ring being erected in a true plane. If such care is not taken the faces of the rings will be distorted; irregular strains will be set up in bolting up the rings and in pushing the shield forward; and loss of time in erecting, as well as broken plates, will result.

Many interesting problems were solved in other sections of the East River Division, but the work has been so fully described that it is not considered advisable to extend this discussion.

J. V. Davies, M. Am. Soc. C. E. (by letter).—When, in the late summer of 1901, Mr. Cassatt returned from Europe with the complete plan of the Pennsylvania Railroad tunnel entrance to New York fully Mr. Davies.

Mr. Davies. developed in his mind, the writer had the honor of being asked to attend a conference in his office with Mr. Rea and Mr. Baldwin (then President of the Long Island Railroad Company), at which Mr. Cassatt first propounded his complete scheme. At that time he had contemplated a location for the station on the east side of Fourth Avenue, but as the writer had previously worked up the plans and investigations for the Long Island Railroad's entrance into Manhattan, he ventured to submit that the grades for the approaches, eastward and westward, would not permit the location otherwise than west of Broadway. This was a disappointment, as, in the other case, the station would have had a position better known to New Yorkers, and would have had an immediate connection with the rapid transit railroad then under construction. The location on Seventh and Eighth Avenues is at present *terra incognita* to the great mass of residents of New York, and the writer ventures to believe that, to-day, after that great station building has been in operation for a year, not 5% of the population has either seen it or even knows where it is located, for reasons best known to our Civic Government.

The influence of the old type of steam railroad stations was not helpful or beneficial to the development of a district, in any of our own or foreign cities, in respect of the immediate surroundings, on account of the smoke, noise, and generally undesirable conditions; but the new development of the Pennsylvania Railroad, with electric power operation at such a depth below the surface, retains to itself all the advantages of business and traffic, with none of the disadvantages of an old-type railroad station. New Yorkers, however, are very conservative, and dislike changing from old habit, and so in process of time they will come to be aware of a magnificent building hidden away on the west side of the "tenderloin" district, and of the facilities there offered for transportation, while if, by a studied system of education, the information is forced upon them, they will be the more ready, so much earlier, to avail themselves of the opportunities provided. With this use of the station must also come a general improvement in the development of the surroundings and properties.

The complete terminal proposition, as presented by Mr. Gibbs in his able paper, concluding the magnificent series of papers on the whole improvement, suggests four sections:

(1) The yard with tracks and platforms;
(2) The station building;
(3) The equipment;
(4) The other structures.

On the first three sections, only, the writer begs to offer a few remarks.

In consideration of the needs of the Pennsylvania Railroad, it must be borne in mind that the great bulk of its business is long-

haul, main-line, traffic, and that, apart from the Long Island Railroad traffic, which is all concentrated at four tracks and platforms on the north side of the station, the Pennsylvania Railroad has practically no suburban business entering this terminal. In the number of passengers, the Long Island Railroad contingent must be far greater than the entire Pennsylvania Railroad business, and yet it is operated with only three tracks (the fourth being used only in emergencies) out of twenty-one platform tracks. The general development of this track terminal is on the established lines of best practice for steam railroads, and is in the same general scheme as the terminal development of the New York Central. The Pennsylvania Railroad, however, has one great advantage over the New York Central in that its car yards for making up trains are only as far from the terminal as Woodside, about 3.4 miles, whereas the Mott Haven Yards are 5.6 miles from the Grand Central Depot, with the added disadvantage of a drawbridge over the Harlem River. In both cases the station and yard tracks, constructed within the heart of New York City, are extravagantly expensive storage spaces for trains, and, if there were no other expense than the taxes, the cost of operation would be very great. Mr. Davies.

In so far as terminal operation is concerned, the Pennsylvania Railroad has an enormous added advantage in the fact that the station is not a terminal, but permits the continued through operation of empties after the unloading of passengers. In addition to 15.62 miles of trackage in the station yard, there is the splendid yard at Sunnyside, covering 192 acres, where all trains are made up, outfitted, and held to await scheduled departures.

With an oppressively paternal governmental administration of public affairs, under which railroads are prohibited from increasing their rates to offset the burdensome taxation and the increased cost of labor, supplies, and materials, and to permit of general improvements in operation, the only possible way a railroad can continue to pay its interest charges is by reducing still further its operating costs. It is difficult to see at the moment how this can be done, but one possibility is that something may be accomplished by getting more actual work out of its car equipment, and it is possible that, with the new electric operation, improved methods of train operation may be developed, for increasing the rapidity of handling trains, reducing the holding time of idle cars (whether Pullman or other classes) in terminal stations and yards, and increasing the movement of train units, which in turn may lessen the necessity for such vast yard layouts in terminal stations, with the enormous consequent cost of construction, as illustrated by the Pennsylvania Railroad improvements and those at the Grand Central Station in course of construction.

The various papers presented to the Society in the series describ-

Mr. Davies. ing this great improvement, have indicated the general evolution of the scheme, but there is one item to which Mr. Gibbs does not refer in relation to the evolution of the station plan, and it is mentioned here because it bears out the great ideas of Mr. Cassatt and Mr. Rea in the development of the finished work from their original ideas. Long before any portion of this scheme was made known to the public, and before any architects were consulted with reference to the station, Mr Cassatt described his ideas as to how the station scheme should be developed, and Figs. 1 and 2 show two sections from the set of sketches made during November and the early part of December, 1901, in the office of the writer's firm, drawn up to illustrate Mr. Cassatt's ideas of development of this general proposition. It will be readily seen from these sections that the final scheme and development has been worked out to correspond almost exactly with the original thought.

The station building is truly a magnificent monument, and an ornament to the City of New York, and, at the same time, it is *par excellence* a station of magnificent distances. Any passenger reaching Seventh Avenue and 34th Street and thinking he is close to his train, whether on the Pennsylvania or Long Island Railroad tracks, will be wofully left if his time is short.

Artistically, one cannot help feeling that, after the beauty and dignity of the main waiting-room and the entrance from Seventh Avenue, the bare steel skeleton forming the train concourse is in the nature of a disappointment, and yet it is difficult to see how else it could have been treated. The stairway connections to the platforms impress one as insignificant and small. It was comforting to all Long Island Railroad passengers to have the Company make radical changes in that end of the station after construction was completed.

Mr. Gibbs has referred to the Hudson and Manhattan Railroad and its function in connection with this undertaking, and the writer is glad to have the opportunity of presenting something on that subject.

About 1890, Mr. Austin Corbin (then President of the Long Island Railroad Company) contemplated extending his road to New York City, and thence to Jersey City, to connect with the Pennsylvania Railroad. At that time Mr. George B. Roberts (then President of the Pennsylvania Railroad Company) held that, for the down-town business of the Pennsylvania Railroad, it was essential that such connection should be made with small cars for rapid-transit service. However, nothing further was done on this project until, in 1897, the Long Island Railroad, jointly with the City of Brooklyn, had a bill passed by the Legislature creating the Board for the Atlantic Avenue Improvement and authorizing the work to be done on Atlantic Avenue, Brooklyn, provided arrangements were made at the same time

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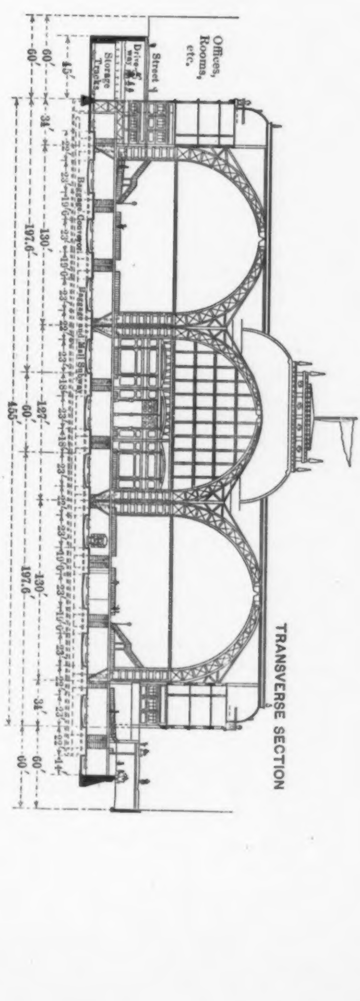

FIG. 1.

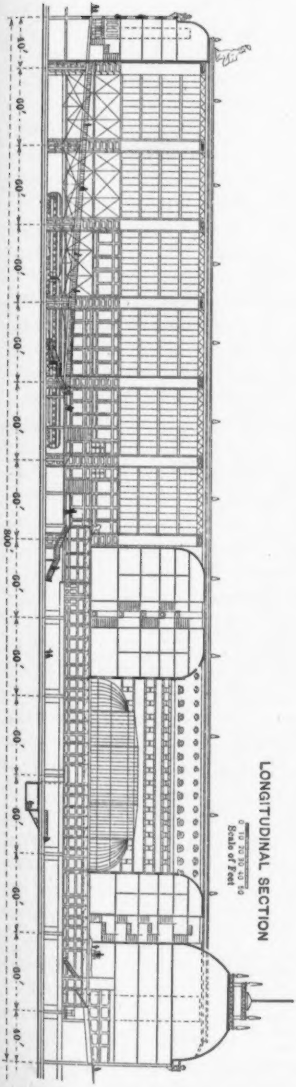

FIG. 2.

Mr. Davies. by the Long Island Railroad for constructing a tunnel from the Long Island Station at Flatbush and Atlantic Avenues, Brooklyn, to and under Cortlandt Street, New York City, the plan being at that time to extend this tunnel to the Pennsylvania Terminal in Jersey City entirely for electrically-operated, rapid-transit service.

The inability of the Long Island Railroad to get the necessary permission from the Board of Aldermen of the City of Brooklyn, delayed procedure on this work to such an extent that, before anything was done, the old Rapid Transit Commission had laid out and proposed to construct the extension of the present Interborough subway to the Long Island Railroad in Brooklyn. This made it unnecessary for the Long Island Railroad to proceed with its intended tunnel, and matters rested until the Pennsylvania Railroad commenced work on its up-town terminal. At about the same time, the New York and Jersey Railroad (predecessor of the Hudson and Manhattan Railroad) was actively proceeding with its work on the up-town tunnels from Hoboken to up-town Manhattan. These arrangements left out of account the down-town business; consequently, the Hudson and Manhattan Railroad extended its lines southward in New Jersey to Pavonia Avenue, to connect with the Erie Railroad, and at the same time entered into an agreement with the Pennsylvania Railroad, whereby it was granted an easement and right of way under the properties and tracks of the Pennsylvania Railroad to a point near the crossing of the Jersey Junction Railroad in Jersey City, and thence over and upon the main-line operating tracks of the Pennsylvania Railroad to Summit Avenue, Jersey City.

On October 1st, 1911, there was put in service the continuous operation of trains from the Church Street Terminal of the Hudson and Manhattan Railroad in New York City to Summit Avenue, Jersey City, and thence over the tracks of the Pennsylvania Railroad to Manhattan Transfer, a distance of 7.6 miles, being 1.1 miles shorter than from the Transfer to the Pennsylvania Station in New York City. This outlet provides a down-town terminal for the Pennsylvania Railroad over the tracks and into the station of the Hudson and Manhattan Railroad. The dividing line in the operation of this service is at Summit Avenue, but the trains run continuously over the tracks of the Pennsylvania Railroad and over the tracks and through the tunnels of the Hudson and Manhattan Railroad from Manhattan Transfer to down-town New York, and, at the same time, by a transfer at Grove Street, Jersey City, passengers can be carried and delivered to any other points in Jersey City and Hoboken, or in Manhattan at 33d Street and Broadway. This plan of operation carries out the ideas of Mr. Roberts and Mr. Rea (at that time Chief Assistant to Mr. Roberts) for the operation of the down-town business as a rapid-transit service. The distance between Manhattan Transfer

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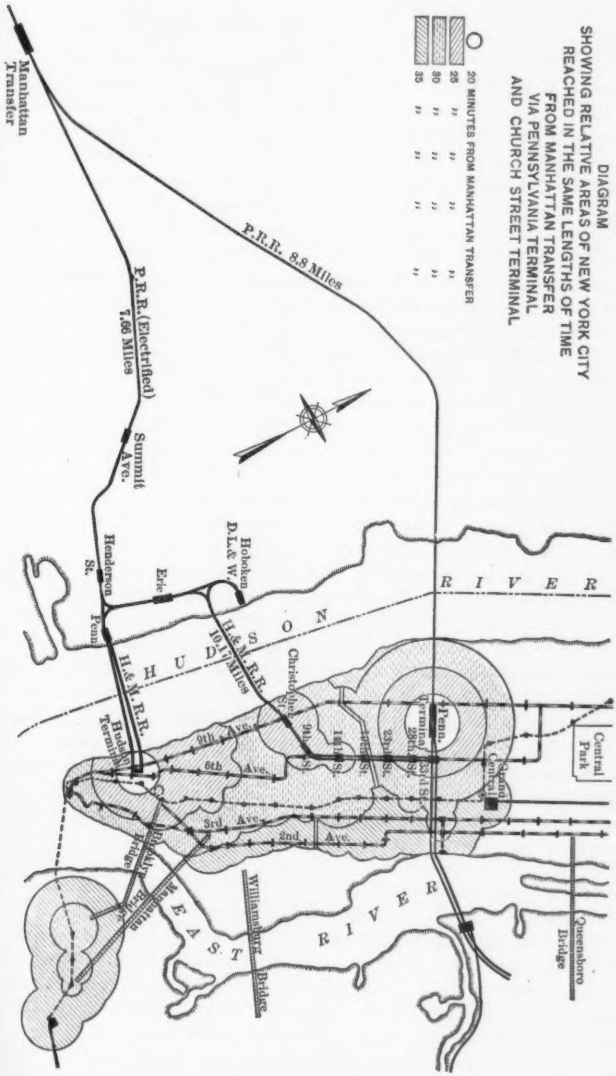


FIG. 8.

Mr. Davies. and Church Street Terminal is easily accomplished at present in 16 min., including stops, and at a later date it may be feasible and desirable to reduce this running time somewhat.

The down-town terminal of the Hudson and Manhattan Railroad is in the heart of the down-town business district, and situated so advantageously in relation to all the distributing rapid-transit lines that it yields at once a rapid and direct route for a very large section of Manhattan and Brooklyn; and the distance is more than a mile shorter from Manhattan Transfer than is the new Pennsylvania Terminal Station; in fact, on this account, it serves a larger territory in less time than the Pennsylvania up-town station, even allowing for the slight advantage of the main-line trains in running at high speed into the Pennsylvania Station. One reason for this is obviously the long time it takes for passengers to walk from any train arriving in the Pennsylvania Terminal to any transit line in that vicinity, and even if the Seventh Avenue Subway were constructed, it would require a longer time interval in getting from a Pennsylvania or Long Island train at the Pennsylvania Station than is required to reach the Interborough Subway through Dey Street from the Church Street Terminal down town.

Fig. 3 shows in a graphic way the relative territories served by the two stations and the advantages of the Hudson and Manhattan route for the business districts of the city.

The principal feature in the Pennsylvania Station which bears consideration and possible criticism is evident from a comparison of the buildings occupying the sites of the two stations. The property on the site of which the Hudson and Manhattan terminal is constructed involved a great expenditure of money, and that railroad was not wealthy enough to consider the earning capacity of its trains alone as being equal to bearing the cost of development of the terminal station without any other source of revenue accruing from that large expenditure. In this respect it differs from the Pennsylvania Railroad. The latter has developed over its terminal station site an enormous building which bears practically no outside revenue returns other than from the operation of the railroad business, as the few stores in the arcades must yield rents which are quite inconsiderable.

The writer believes that it is a matter of pride to the officers of the Pennsylvania Railroad that they have no rentals of any kind accruing from their property, and that the property is considered solely as a betterment of the railroad system. It seems to the writer that this is the wrong point of view. From the standpoint of stockholders in the Pennsylvania Railroad Company, the writer feels that they are entitled to obtain any reasonable return which their investments can earn from any source not inconsistent with carrying on the business of the railroad as a prime feature and necessity. Subordinating every-

Mr. Davies.

thing else to that railroad operation, then it appears to him, that they should get other returns for the enormous investment for land and buildings upon that land. There can be little question that the buildings, with offices of a dignified and proper character, would have yielded, not only rentals which would have assisted in the payment of the operating expenses of that station, but would have created a new center of activities in the neighborhood of the station, and would have also directly increased the transportation business of the railroads terminating at or operating through the station.

An illustration of this is given by the success of the terminal buildings of the Hudson and Manhattan Railroad at its Church Street Terminal. When this property was purchased for station purposes it was thought to be out of the way, and the street was little known. While it is within 200 ft. of Broadway, it was never considered as a regular thoroughfare, and was never looked upon as being directly within the select populous down-town district of Manhattan. Within three years of the opening of the Church Street Terminal, the buildings have been rented to their absolute limit, that is to say, at the present time they are 100% rented in respect of all rentable space of every kind whatsoever, and there are practically 10 000 people doing their daily business in the offices and on the premises. The rentals accruing from such office space are very important as an asset of a railroad such as the Hudson and Manhattan, and, beyond all question, would not be disregarded by such a corporation as the Pennsylvania Railroad. It would hardly have cost more to have constructed the Pennsylvania Station with office accommodations (or, on the English theory of hotel construction at railroad terminals, to have built a hotel on the site) than the immense building which the Pennsylvania Railroad has constructed exclusively for itself.

In the general situation of this Pennsylvania Station there is little doubt that the Company will command to that station the bulk of the long-haul business which naturally originates in the up-town district. This, for the most part, is business of a class which comes to and leaves the station by cab, carriage, or motor, and is in no respect a rapid-transit business. On the Long Island Railroad end, the Company will command the up-town shopping and theater business of the Long Island Railroad and the North Shore business, the latter being badly in need of rapid-transit facilities at that point. At the same time, the down-town business from all points of Long Island east of Jamaica is now, and will continue to be, served more quickly and more advantageously by way of Brooklyn. The great remainder of the down-town business of the Pennsylvania Railroad must continue in its present direction and be served by the Hudson and Manhattan Railroad.

In the matter of track and signal work in the Pennsylvania tun-

Mr. Davies. nels, the Company had some advantage due to the fact that the Hudson and Manhattan line was in operation before the Pennsylvania had to equip its tunnels. In respect to the signals, the Hudson and Manhattan was under a disadvantage, in being the experimental ground for the new types of signal movements, particularly in respect to the electro-pneumatic relays; and it is not unfair to say that nearly the whole of the original installation, put into the Hudson and Manhattan tunnels, was changed by the signal companies for newer types as the types were developed for the Hudson and Manhattan and Pennsylvania systems. This perfection of the apparatus has been really remarkable with respect to the electro-pneumatic signals of the Hudson and Manhattan, and is well worth noting. For the 12 months ending August 31st, 1911, with this apparatus, the failures of signals have been only one to 1 066 463 movements, and the failures of stops have been only one to 3 153 114 movements; and, in the same period, there have been only two failures of switch and lock apparatus, or one failure to 2 021 510 movements. It is only fair to say, with respect to the all-electric apparatus installed in portions of the Hudson and Manhattan tunnels, that similar results have been obtained, both as to signals and stops.

The Hudson and Manhattan had not been operating long when the Pennsylvania committee came to its decision on the track, but at that time it seemed obvious, from the committee's experience, that the ballasted track through the tunnels, using concrete only at stations and on curves, was the desirable installation. In the Hudson and Manhattan tunnels the cost of track on ballast averaged approximately \$6 per running foot, using an 85-lb. rail of the Am. Soc. C. E. section; and the cost of track on concrete foundation averaged \$7.50 per running foot, with a rail of the same section. The difference between these figures and those given by Mr. Gibbs as the cost of the track in the Pennsylvania tunnels probably represents the heavier rail section installed in the latter, the somewhat longer ties, and the greater quantity of concrete per running foot.

One difficulty which has been found with concrete track on the operating road, apart from the stations, where the speed is low, is that the superstructure becomes loose on the concrete foundation, and "pumps." The screw-spike, as first used by the Hudson and Manhattan, was very similar to the Pennsylvania standard, and followed the lines of the general type, consisting of a round $\frac{7}{8}$-in. bar, one end of which was upset into a circular flange, $2\frac{3}{8}$ in. in diameter, and a 1-in. square head. The body of the bar was swaged down to $\frac{5}{8}$ in. to form the threads of the bar. Though this spike gave fairly good results on straight track, it was found to be too weak to withstand the lateral thrust of the cars on curves. This was especially noticeable on curves where the ties were embedded in concrete. As a general rule, the

spikes broke at a point where the swaging was fully developed, which in all probability was due to a partial injury to the metal when the spike was first driven, it having become bent while being drawn up to the base of the rail, and this bending increased under traffic, until finally it broke. Another bad feature of the spike was the small head used for driving. In many cases, before the screw-spike could be driven home, the edge of the spike head became so chamfered that it was impossible to get a purchase with the socket wrench, and in consequence of this condition it was almost impossible to withdraw the spike. To renew this broken spike it was necessary to drill through the tie-plates and drill new holes in the ties in order to insert new spikes. It was decided, therefore, to make a radical change in the design of the spike in order to meet these defects. The diameter of the spike is now 1 in., and about 1 in. below the head the metal is swaged down to $\frac{3}{4}$ in. to form the threads. (Fig. 4.) It has a hexagonal head, $2\frac{3}{4}$ in. on its longest diameter, the under side of the head being formed to an angle to coincide with the base of the rail. In conjunction with this screw-spike, a cast-iron filler is used, the upper side of which conforms to the under side of the screw-spike, and the whole washer is tapered slightly toward the rail. The effect of this washer is to do away with the bending of the spike, and the slight taper tends to force the spike head into good contact at the rail base. It may be of interest to note also that the new spike costs less per pound than the one originally used, and appears to have overcome all its defects. Mr. Davies.

The development of special track construction by the use of cast manganese steel, and more recently by the perfecting of rolled manganese steel, introduces an interesting point regarding which a word might be added. Though cast manganese for special track construction has the great merit of excellent wearing qualities, the uncertainty of its texture and the clumsiness of the sections necessary to the casting of this material into rails and switch points, has made it desirable to develop further the use of rolled manganese steel in connection with such work. This work has been elaborated quite considerably on the Hudson and Manhattan system, especially in switch and stock rails. The manganese castings, however, are particularly suited to frog and guard-bar construction, and have been retained for this purpose.

Mr. Gibbs states that on the Pennsylvania work the switch points are housed in the stock rail. This housing is accomplished by planing down the stock rail to accommodate the tapered switch point. The stock rail housing of the switch points used by the Hudson and Manhattan is accomplished by an offset bend in the stock rail, the offset being sufficient to accommodate a $\frac{3}{4}$-in. blunt switch point. (Fig. 5.) The point is made up of a rolled manganese rail with a manganese casting which forms a guard-bar and lines up the guard-rail. There is also a manganese guard-bar which forms the housing for the switch

Mr. Davies.

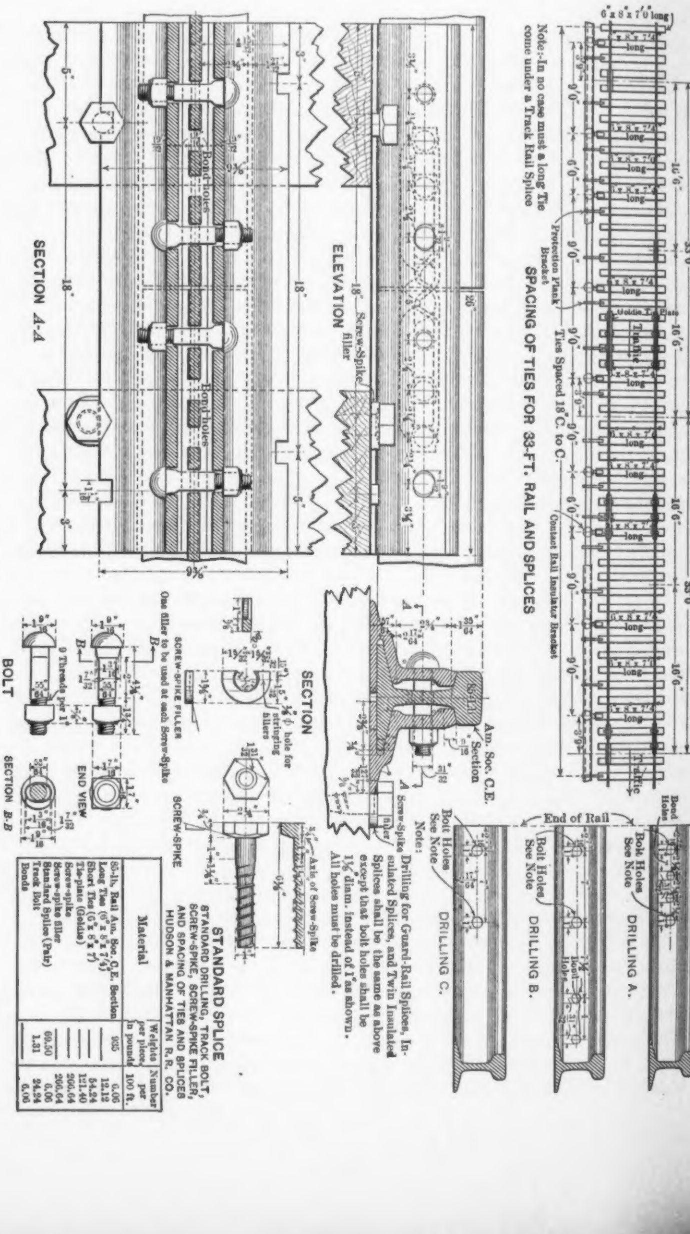
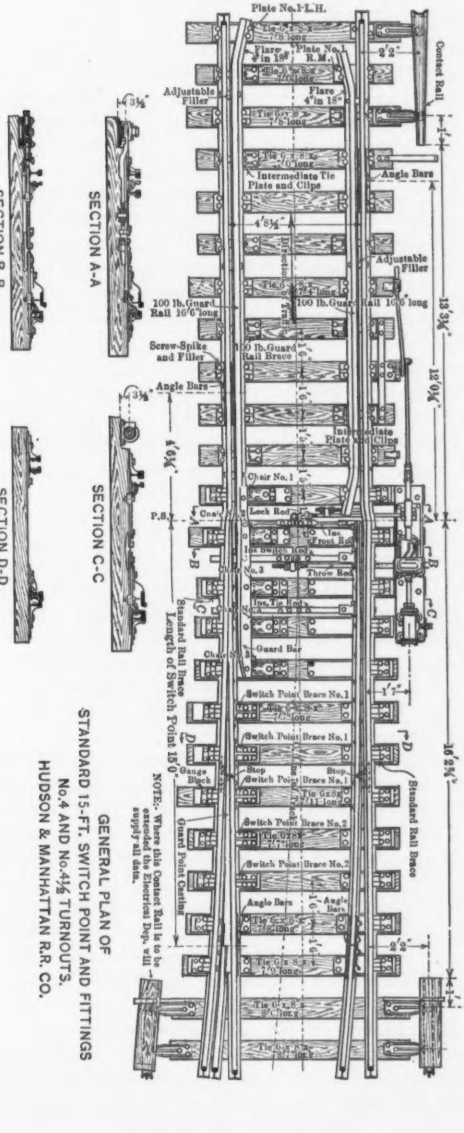


FIG. 4.

Mr. Davies.



GENERAL PLAN OF
STANDARD 15-FT. SWITCH POINT AND FITTINGS
No.4 AND No.4½ TURNOUTS.
HUDSON & MANHATTAN R.R. CO.

FIG. 5.

Mr. Davies. point when it is thrown in the reverse position. This arrangement gives a guard-rail effect all the way through the turnout, and has proved highly satisfactory in service. The guard-bar point housing for the reverse position of the switch also allows of a much smaller throw, only 2¾ in., instead of the usual 4 in., being used.

In regard to the ventilation of the tunnels, the writer regrets that Mr. Gibbs has not carried this subject a little further, and given the air pressures obtained in running through the tubes. As a commuter on the Long Island Division, this question is one of personal as well as professional interest. When the Long Island Railroad started to run its trains through the tunnels, the operation was extremely rapid on the heavy grade descending from the surface to the tubes in Long Island City, so that at the moment of entry into the tubes the speed was very great and the resulting pressure was such as to cause every passenger to rub his ears. Since operation was commenced, it appears as though the speed has been materially decreased, as the pressures are not as noticeable now as in the earlier days of operation. The Pennsylvania tunnels constitute an ideal layout for the adopted "Saccardo" system of forced-draft ventilation by the use of blowers, forcing in air in the rear of trains through an annular opening, representing practically the principle of an injector. This system, however, would not have been suitable or possible in the case of the Hudson and Manhattan tunnels, and in that undertaking there was adopted the general system of subdividing the tubes throughout to maintain a continuous movement of the column of air in one direction. This system is broken only at stations and enlargements, and, to offset this difficulty, exhaust fans have been installed at all such points, to which the action of trains forces the columns of air; and there are also blowers to force in fresh air in the rear of trains at points of entry into the tubes. The result of this method has been entirely satisfactory.

In other places, such as the terminal station at Hoboken, Pennsylvania Station in Jersey City, and Church Street Terminal, New York City, where, under normal conditions, there may be "dead" spots in the ventilation, local blower systems have been installed either for exhausting air from these local points or for forcing in fresh air to replenish the supply. In other places, direct openings to the outer air are provided to permit the train action to force the air out of the tunnels.

Since the opening of the Hudson and Manhattan service over the tracks of the Pennsylvania Railroad to Manhattan Transfer, the writer has made some very interesting experiments in relation to wind and air resistance to moving trains, and as to the pressures of air in the tubes at varying speeds. Unfortunately, the figuring of the results of these experiments has not been completed, so that they cannot be

Mr. Davies.

presented fully, but the general information will be of material interest. The cross-section of the Hudson and Manhattan cars represents practically 56% of the open cross-sectional area of the tube tunnels, and 54% of the cross-sectional area of the subway sections which are lined with concrete. The diagram, Plate CXVII, represents two separate runs, eastbound and westbound, between Manhattan Transfer and Church Street Terminal. These tests were made during the night hours, when the wind was blowing at the rate of from 10 to 15 miles per hour, and there was considerable rain.

The first point of interest to note is the increase in pressure for the same speed when running against the wind in crossing the open Hackensack Meadows on perfectly level and tangent track, as compared with running with the wind; that is, an increase from 0.75 to 1.30 in., water gauge, for a speed of 40 miles per hour, indicating the

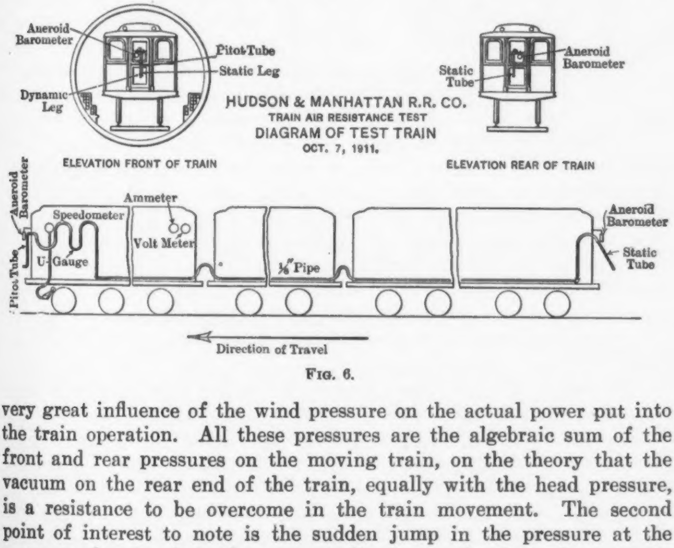


FIG. 6.

very great influence of the wind pressure on the actual power put into the train operation. All these pressures are the algebraic sum of the front and rear pressures on the moving train, on the theory that the vacuum on the rear end of the train, equally with the head pressure, is a resistance to be overcome in the train movement. The second point of interest to note is the sudden jump in the pressure at the moment of entry into the concrete-lined tunnel, when the pressure at similar speeds jumps from 0.30 to 1.25 in., water gauge, indicating the resistance due to putting in motion the column of air through the concrete tunnel, being the distance from the portal at Waldo Avenue, Jersey City, to the open connection and enlargement at Grove Street Station, Jersey City, a length of only 3 958 ft. The third noticeable fact is the enormous jump and the continued pressure resistance at the moment of entry into the iron-lined tube immediately east of the Pennsylvania Station, Jersey City, when the air pressure

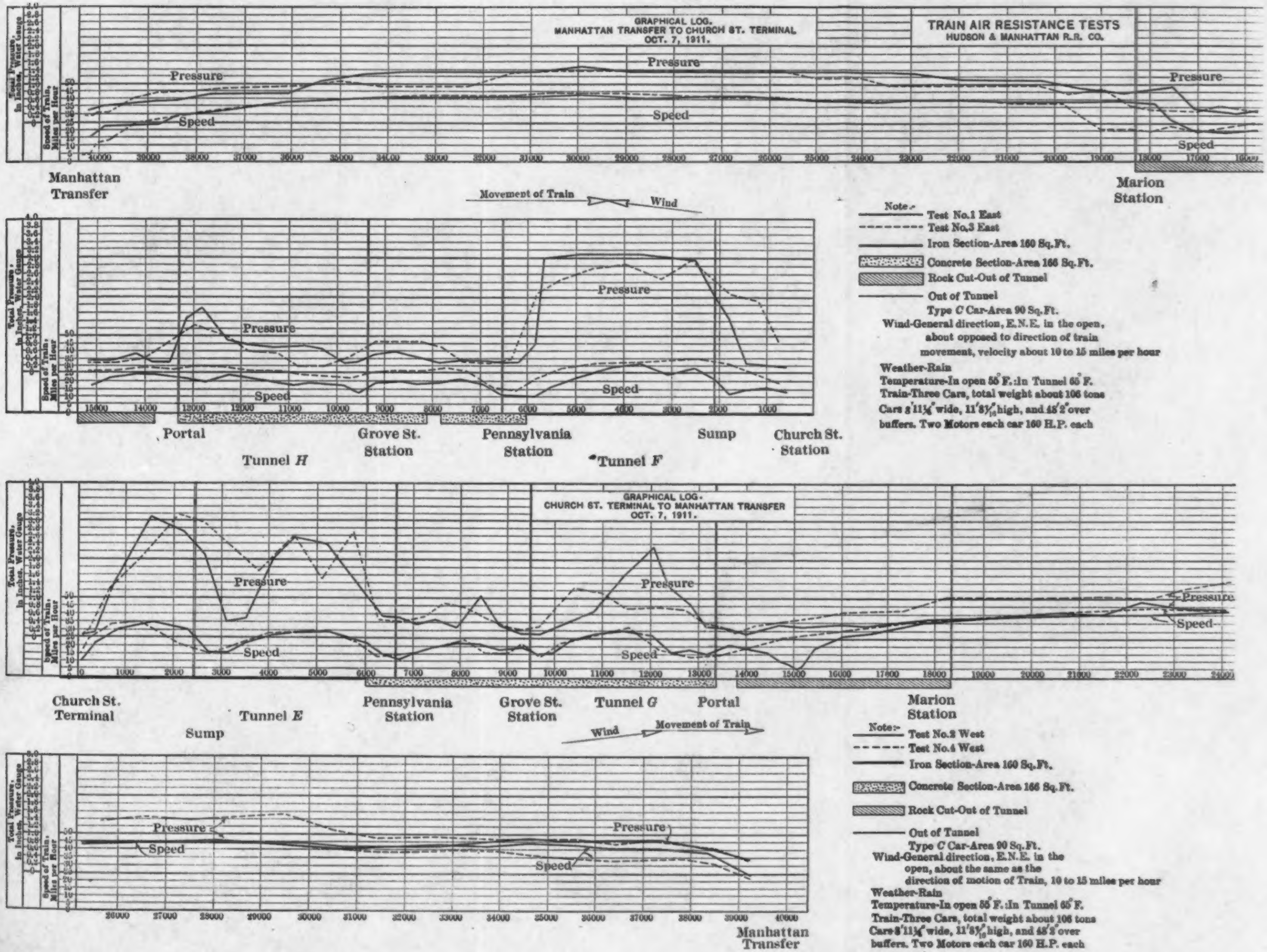
Mr. Davies. at similar speeds suddenly increased from 0.30 to 2.60 in., water gauge.

In this case there is some 6 000 ft. of continuous tube tunnel through which the column of air has to be forced by the train movement, although this is assisted to some extent by a suction fan at the Church Street Terminal.

Further experiments, at other times, on the varying pressures of the air column at varying speeds through the tube tunnel, seem to indicate that, for a tunnel section of which a car section represents 56% in cross-section, a train would not be able to operate at a speed exceeding 45 miles per hour with any possible motor sizes which could be put on the car axles, in the present state of the art, so as to yield power sufficient to drive the column of air, if more than 2 miles in length, without some special and new types of air blowers to exhaust the air in front of the train and to force air in behind it to relieve the wind resistance. These experiments indicate quite clearly that the ventilating system installed by Mr. Gibbs in the Pennsylvania tunnels probably results in an economy in power consumption in the operation of trains, due to keeping the air columns in motion ahead of and in the direction of train movements, thereby reducing materially the power consumption required for the movement of trains. Such a system, however, while especially applicable to a proposition such as the Pennsylvania tunnels, would not be applicable without considerable difficulties and complications in such a proposition as the Hudson and Manhattan tunnels, which involve an entirely different and very complicated system with respect to the question of ventilation.

In connection with the ventilation of the tunnels, it is most interesting and valuable to note the cool summer temperature, and the constancy of that temperature, in the tubes of the Pennsylvania Railroad, as well as in those of the Hudson and Manhattan system. In the latter tunnels the temperature varies only a few degrees between summer and winter, and the reason for the low temperature the writer attributes to the fact that the exterior lining is in every case in direct contact with the moist exterior soil, permitting radiation and absorption of the heat from the tunnels into the ground, in direct contradistinction to the constructive plans of the Interborough Rapid Transit subway, where, in addition to using hollow tile in contact with the exterior soil, the walls are constructed with a vertical wall of vitrified electric ducts exterior to the entire subway structure. In the case of the subway, the arrangements could not have been more perfect for maintaining a high degree of temperature by preventing any possible absorption of the interior heat into the exterior soil. Furthermore, the circulation of air, through the tubes of the Pennsylvania Railroad and the Hudson and Manhattan Railroad, permits the operating trains to push the air through the tubes, forcing it out at any openings; whereas the arrangement of the four-track subway, with no diaphragm walls or

PLATE CXVII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXIX, No. 1166.
DAVIES ON
NEW YORK TUNNELS, PENNSYLVANIA R. R.



other division between the operation in opposing lines of direction, simply churns up the air and keeps it within the subway to be heated up continuously by the additional heat given off by the operation of trains, by the passengers in the cars and stations, and by the churning and eddying of these conflicting air currents. Mr. Davies.

WILLIAM J. WILGUS, M. AM. SOC. C. E. (by letter).—Mr. Gibbs has described in a most comprehensive manner the intricacies of design and construction of one of the world's great terminals; and, in commenting on a few of its broader features, the writer desires to express his admiration for the foresight and courage of the late A. J. Cassatt and his associates in conceiving this notable engineering project and in bringing it to a successful conclusion. Mr. Wilgus.

The location of the station, between Seventh and Eighth Avenues, was made no doubt for good and sufficient reasons; but it would seem to the casual observer that the advantages that would have accrued to the railroad and the public by having the entrance nearer the main arteries of city travel would have warranted the resulting relatively small additional expense and grade modifications.

Presumably, the adopted location was influenced by the very natural conclusion that the Public Service Commission would lay out the so-called Tri-borough Subway System so as to serve the neglected "West Side," *via* Seventh Avenue. The failure of the Commission to follow this logical course is incomprehensible. Not only is the usefulness of the Pennsylvania terminal seriously handicapped, but an important section is denied the convenience of rapid transit, and the city is deprived of the benefits of increased taxable values which always follow improved transit facilities.

However, even with an assured subway route in Seventh Avenue, a station location extending eastward instead of westward therefrom has many advantages, for ignoring which the railroad company no doubt had convincing reasons.

Mention is made of the lack of provision for "unlimited car storage." This raises a question that is very perplexing in the design of important terminals in the heart of a large city. Two horns of a dilemma usually present themselves. Either enormous sums must be expended in land and construction for car storage yards adjacent to the terminal, or the capacity and usefulness of the accessorial tracks must be seriously reduced, and operating expenses and risks increased, by "dead-heading" trains to outlying storage yards. Too often the latter alternative is selected without balancing properly its merits and demerits as compared with the former. For instance, assume a congested situation where one-quarter of the train movements between the terminal and the outlying storage and cleaning yard for a distance of 6 miles are "dead-head," and assume that the cost of construction of the connecting tracks is $21 000 000. It will at once be seen that

Mr. Wilgus.

the elimination of the dead-head movements would increase the capacity of the line for handling revenue trains one-third, representing an investment of, say.................................. $7 000 000

To this add the capitalized cost of operation, maintenance, and risks, say $200 000 per annum at 4%.............. 5 000 000

$12 000 000

Under the assumed conditions, therefore, it appears that an expenditure of $12 000 000 for storage and cleaning facilities adjacent to the terminal would be justifiable, provided that by so doing the dead-heading of trains could be largely obviated. In this connection, sight should not be lost of the superior advantages of a contiguous location, as regards convenience, flexibility, and uninterruptedness of car supply.

In the case of the Pennsylvania terminal, undoubtedly this aspect had full consideration, and it will be interesting to have the reasons that determined the restriction of storage capacity at the station.

The absence of provision for seats in the main waiting-room is a departure from the usual American practice. While it has many advantages (for instance, freedom from obstruction to passengers passing between the ticket offices and trains), it lacks the cheerfulness, and the opportunity for mutual observation, which are elements of attractiveness to travelers.

The general design of the building is one that prompts comment. Since electricity has come into use for trunk-line operation, a vital question has arisen: Shall the structure be of the low monumental type, thus adhering to the old standards which were the outgrowth of the necessity for wide open expanses for dissipating the products of combustion from steam locomotives; or shall it be of the revenue-producing type, preserving intact its main purpose as a transportation gateway, and at the same time reaping for the stockholders the beneficial use of valuable overhead space?

This question faced the writer when he first proposed the rebuilding of the Grand Central Terminal in 1902, after the decision had been made to change the motive power from steam to electricity, and he then advised a manner of treatment of the station and surroundings that would permit the utilization of the "air rights" as a by-product of electrification. It was shown that in this manner the company would ultimately reap from increased values and rentals a return far more than sufficient to pay for the entire cost of the improvement. Ultimately, this view was adopted, and the structures are being designed and built so that, as desired, the overhead spaces or "air rights," including the main station, may become revenue producers without impairing the usefulness of the lower levels for railroad purposes.

It certainly seems unwise not to seize the boons that accompany the use of electricity, even though it does become necessary to violate preconceived notions which have been founded on eighty years' association with steam, but are not applicable to changed conditions. The railroad, after all, is a commercial institution, and no legitimate source of revenue should be ignored that does not interfere with the prime object, transportation. Mr. Wilgus.

In fact, it is the use of electricity that makes possible, not only the reclamation of air rights, but also the growth of capacity and compliance with the demands of public convenience, at the terminals of expanding systems like the Pennsylvania and the New York Central. In the latter instance, the continued use of steam would have imposed an expenditure for a widened open area of costly land and for a duplicate tunnel, largely in excess of the cost of electrification with its "open sesame" to double-track levels, increased track capacity, utilization of overhead spaces, comfort to passengers, and civic development.

Arguments against electrification in great centers of population have too often dwelt on the enormous cost of accompanying improvements, without making plain that with adherence to steam the collateral costs for equivalent facilities would be far greater, and furthermore would deny the opportunities offered by electricity for increasing revenue and keeping step with human progress.

Regarding stairways between the track platforms and the concourse, it is evident that at a through station, like the Pennsylvania, they are an unfortunate necessity. This draws attention to the fact that, with all their disadvantages, stub tracks at terminals have the merit of avoiding this fault. At the Grand Central Station the grade of the upper level of tracks for "through" trains was fixed so as to retard inbound and accelerate outbound traffic, and at the same time permit the use of easy ramps between the track platforms and the concourse.

It is interesting to note that ballasted track was adopted in the tunnels, although an experimental section with a concrete base has been installed in a land section of two of the tubes. At the Detroit tunnel the concrete type was adopted as a result of several years' experience with a test section on the Toledo Division of the Michigan Central Railroad, and the results thus far have been eminently satisfactory. Not only is the concrete type more sanitary and less costly to maintain, but it also affords the opportunity of lessening the size and therefore the cost of the tunnel. At Detroit the maximum depth from the top of rail to the intrados of the arch is 2 ft., whereas the ballasted type of track requires 3 ft.

As regards electrification, the reasons given by the author for the adoption of the "direct current" system seem conclusive. Local conditions very properly governed. This principle manifestly should guide the decision rather than an academic dictum that some "standard"

Mr. Wilgus. should be followed regardless of its applicability to special circumstances. In this connection, the information on the reliability of electric operation, furnished by Mr. Edwin B. Katte of the New York Central, and by Mr. B. F. Wood of the Pennsylvania Railroad, at the last Annual Meeting of the American Institute of Electrical Engineers, is interesting and instructive.

Mr. Churchill. CHARLES S. CHURCHILL, M. AM. SOC. C. E. (by letter).—Mr. Gibbs' paper is so complete in its description of the ventilating plant installed in these tunnels that there is scarcely anything that can be added to it. The writer thinks it is well, however, to call attention to Mr. Gibbs' statement, to the effect that it was considered of great importance, not only that the tunnels should be safe under all emergency conditions, but that there should be at no time noticeable discomfort to passengers.

One emergency condition especially provided for is the case where a train is stopped for any reason at or near the middle of one of the tunnels and held there for some time. In this case, although the traffic may be very heavy and the weather warm, the piston action of this train is not available for ventilation. The fans, however, are arranged so that, even if they are not in operation at that particular time, they can be immediately set in motion, delivering through the various tunnels the quantities of air given in Table 4.

Take, for example, one of the East River tunnels: the delivery of fresh air between the Long Island and Manhattan shafts by the fans through one of these tunnels is about 65 000 cu. ft. per min., which is equivalent to a linear velocity of 295 ft. per min. The most recent test reported to the writer was a case where the train was purposely standing in the middle of the East River tunnel, and although the train to some extent blocked the free passage of fresh air, it was observed that the movement of the air from the middle of the tunnel to the Manhattan shaft was at the rate of about 233 ft. per min. This is the only additional matter that the writer finds it important to record.

The special feature in the design and construction of these New York tunnels is that they have been equipped with every known device needed to make them safer and more comfortable than any like construction heretofore undertaken.

Mr. Henderson. G. R. HENDERSON,* ESQ. (by letter).—Mr. Gibbs' paper is so complete and full of interest, giving so much exact detail as to the various unit quantities, that it is impossible to discuss more than a few of the points brought out. The data embodied will be of great value for reference, and, considering the magnitude of the work, will be very thankfully received by the Engineering Profession generally, particularly in consideration of the great labor of compiling it and putting it in shape.

* Mechanical Engr., Baldwin Locomotive Works.

There is one point which appeals to the writer, particularly, and that is the decision as to the type of electric locomotive which was finally adopted, as illustrated on Plate CXIII. It was only a few years ago that a high center of gravity in a locomotive was considered a thing to be avoided, and people looked askance at the development of the "greater locomotive," with its large boiler poised high above the wheels, in a number of cases the center of the boiler being at least 10 ft. above the rail. There have been cases of locomotives overturning from the effect of centrifugal force, when running at high speeds on curves, and safety and a low center of gravity were generally supposed to be synonymous terms. When, a few years ago, an electric locomotive with a very low center of gravity was derailed in the outskirts of New York City, with considerable consequent damage, it began to be recognized that, in some respects at least, the high center of gravity of a locomotive constituted a factor of safety. Mr. Henderson.

Like all other problems, this, of course, depended on the point of view which was taken, and, while a low center of gravity does insure safety against the overturning of the locomotive in rounding curves at high speeds, yet a high center of gravity, conversely, insures the integrity of the track by causing much less strain on the tie-plates, spikes, and fastenings securing the rail to the ties, as the increased pressure on the outer rail, due to centrifugal force, increases the frictional resistance of the rail on the ties, thus reducing the strain on the fastenings.

It seems that even this may be of benefit on straight track, and the diagram, Fig. 19, shows that the side pressures against the rail are five times as large, apparently, as those caused by a locomotive with a higher center of gravity. It is understood, incidentally, that in many cases the lateral pressures were more severe on straight track even than on curves, and, although it is difficult to explain this satisfactorily, the records prove beyond doubt that such was the case.

The electric locomotive which was finally adopted had a center of gravity nearly 64 in. above the rail, whereas the locomotive with which the first experiments were conducted had a center of gravity only 42½ in. above the top of the rail, and it is interesting to note that the locomotive with the high center of gravity gave approximately the same lateral pressures as the steam locomotive having a center of gravity of the same height.

While speaking of the location of the center of gravity, it may be of interest to call attention to the fact that its height can be determined very readily on a track scale by first weighing the locomotive and then elevating one rail about 6 in. and supporting this over the dead rail and the pit wall, thereby weighing one side of the locomotive, and from the augmentation of the load on the lower rail

Mr. Henderson. above that due to the engine in its normal position, the height of the center of gravity may be at once determined by simple trigonometry. This is so much quicker and so much more accurate than the tedious method of computation, or the dangerous method of suspending the engine on pivots, that it seems strange that it is not more frequently resorted to.

There seems to be a great mechanical advantage in consolidating the power in one motor which is above the running machinery and can be easily removed and replaced without dropping wheels or pulling armatures off the driving axles. The greater accessibility regarding electrical connections has also much to recommend it to an operating official, and the writer believes that the Pennsylvania Railroad is to be congratulated upon developing and installing a machine of this type. The running gear resembling so closely that of an ordinary steam locomotive also makes it easier to be cared for by the engineer, so that it seems to the writer that this arrangement gives a combination of maximum stability, electrical efficiency, decreased maintenance, and accessibility for making repairs, which is embodied in few other types of electric locomotives.

Mr. Katte. EDWIN B. KATTE,* ESQ.—In conjunction with the recent paper by W. J. Wilgus, M. Am. Soc. C. E., descriptive of the New York Central and Hudson River Railroad Company's new terminal and electrification,† and with the account of the Washington Passenger Terminal,‡ by W. F. Strouse, M. Am. Soc. C. E., Mr. Gibbs' paper makes a very interesting permanent record in the *Transactions* of the Society of the progress of modern trunk-line railroad practice.

To electrical engineers the most interesting feature of this great improvement is naturally the system of electric traction adopted. The fact that the third-rail, with direct current, was finally installed after a thorough investigation of the design, construction, and operation of a single-phase system on a steam railroad having a heavy service, as compared with a similar service handled by direct current, is gratifying to those who had previously expressed their belief in the direct-current system. This is especially reassuring because the installation is not only for terminal use, but also for trunk-line electrification, with the multiple-unit train runs gradually lengthened to the remote ends of Long Island, and the electric locomotives operating to Harrison, N. J., with a contemplated extension on the main line to Philadelphia.

The section designed for the third-rail is unusual, and the casual observer might wonder why a rectangular section had not been used as it would offer equal facilities for splicing and bonding and, at the

* Chf. Engr., Electric Traction, New York Central and Hudson River Railroad.

† *Transactions*, Am. Soc. C. E., Vol. LXI, p. 73.

‡ *Transactions*, Am. Soc. C. E., Vol. LXXI, p. 11.

same time, be more readily protected from accidental contact. Even greater protection could have been afforded by an under-running third-rail contact. **Mr. Katte.**

The locomotives are more interesting from the mechanical than the electrical standpoint. The motors, control, wiring, etc., are of tried designs, and will prove reliable and economical. It is the mechanical features which are novel, at least in the United States, and there are those who have questioned the possibility of maintaining in line the very heavy jack-shafts, with their large counterweights. Should the boxes be allowed to become loose, due to wear or lack of careful adjustment, the unbalanced effect of the heavy counterweights might be expected to have some effect on track maintenance. However, only time can show what the operation of these locomotives will develop; up to the present, the speaker has only heard the most encouraging reports. Two years from now, further advice from Mr. Gibbs will be most helpful to the Profession.

George A. Harwood, M. Am. Soc. C. E. (by letter).—After reading Mr. Gibbs' paper, the writer has concluded that there is very little left to discuss, as it is a most complete description of a very complete terminal. Several other papers have been written on the different elements going to make up the New York improvement of the Pennsylvania Company, but this one tells the entire story clearly and in a manner which can be understood by one who is not a specialist in any of the features required in the complete installation. **Mr. Harwood.**

Some criticism has been made by laymen and others on the location selected for the terminal station, but most engineers know that it is easy to criticize, if one is not responsible for the solution, and, while it would have been of great adavantage to both the public and the Pennsylvania Railroad if the station could have been located nearer an existing rapid transit line of the city, it should be remembered that there are not many sites, of the size required for this improvement, available in the City of New York at a price which makes them feasible to consider, and that, in addition, an improvement of this magnitude will eventually create a new center and new routes for rapid transit lines; so that this criticism is of a temporary character only, and the Pennsylvania Railroad has made a very long step in advance in locating its station as this one is, instead of continuing to depend on ferry connection from New York City to its Jersey City terminal.

Some criticism has also been made of the stair-climbing required, but this is only a matter of detail, and there is no doubt that, after sufficient time has elapsed for observation, the engineers of the Pennsylvania Company will correct this difficulty in an entirely satisfactory manner.

Mr. Harwood.

The Committee which made the original assumptions as to size and capacity has taken a broad view of the future, and the results indicate that there is a most ample opportunity for increase in business. There is some question in the mind of a man not familiar with the details as to whether it would not have been wise, at least during the early years of the terminal operation, to have combined the Long Island station facilities with those of the Pennsylvania Railroad, in order to have effected economy in operating expenses, and left the development of the independent Long Island station until the business more nearly reached the capacity of the main station. It is also questionable if it would not have been better to have provided a somewhat more flexible track arrangement by connecting the two tunnels west of the station to a greater number of tracks. These are only thoughts which suggest themselves to the writer, and could not be considered as criticisms without knowing the reasons which governed the men charged with the responsibility for these decisions in arriving at their final conclusions.

It is gratifying to note that advantage has been taken of the possibility of developing the air rights on a large part of the terminal area. This feature is one of the most important results of electric operation as applied to trunk-line railroads, as the old-fashioned train-shed required for steam operation is no longer necessary, and the areas above a reasonable clearance height over moving equipment may be developed commercially, thereby reducing the enormous capital cost of the city station, which, in turn, permits the railroad companies to give to the public much finer and more accessible terminals.

A very generous side clearance has been allowed, and it seems to the writer that, in a terminal of this character, a minimum of 6 ft. from the center of the track on tangents, with compensation on curves to give an equivalent clearance line, is sufficient and is warranted on account of the very high cost per unit of car-standing space.

Two of the most excellent innovations, which the writer believes will be used hereafter throughout the country in large city terminals, are the high platforms and permanent concrete track construction. In addition to the saving in energy for the passengers in not having to descend and climb an additional 4 ft., it has been demonstrated by numerous tests that a very material saving in time is effected where passengers leave trains on a level with the car platform, and this is an important feature in a terminal, designed to be used as a through station, as this is. The concrete track construction is equally important on account of its cleanliness and freedom from constant maintenance charges, the absence of which will pay for the high initial cost long before the limit of the life of the construction has been reached. The Pennsylvania, New York Central, and

Mr. Harwood.

Michigan Central, for its Detroit River Tunnel, began experimenting with concrete track construction along about the same lines some years ago, and experience has shown that this type of construction has stood up most excellently under quite excessive service. The design used by the New York Central is very similar to that which Mr. Gibbs has illustrated, except that it has been found unnecessary to attach the creosoted blocks to the concrete by anchor-bolts, and also that there is some economy in using an independent block for the support of the third-rail instead of one longer continuous block supporting both the running track and the third-rail. On long stretches, this type of track can be built for about $6 per lin. ft., as compared with $8.94 for the Pennsylvania track. A considerable portion of the difference, however, is accounted for by the fact that the New York Central track has been laid on top of a steel deck which has probably reduced the quantity of concrete in the base, as there was undoubtedly considerable irregularity in the rock excavation where the Pennsylvania track is laid, and, in addition, some of the details have been simplified. The cost of first-class ballasted track of the type which both the Pennsylvania and New York Central have used in their terminals will probably run from $3.25 to $3.50 per lin. ft., so that it can be seen that a very excessive amount is not involved in using the permanent concrete type. Mr. Gibbs states that he has used No. 8 frogs almost entirely, and, the writer's experience indicates that, with the large sizes of equipment now used, this is about the maximum angle which should be installed for terminal operation.

The quarters required for housing the numerous employees about the yard are apparently in separate buildings, located at points where they are considered to be most convenient for the men. There is some question as to whether this practice is as good as a large centrally located building, with the main tower, yardmasters, engine dispatchers, and other yard-operating employees, who have to work more or less together, located therein, supplemented with a few scattered buildings for the maintenance men.

It is interesting to note that both the Pennsylvania and the new Grand Central Terminals have been designed so that they are equivalent to through stations, and these layouts, in addition to providing convenient means of turning through trains made up of special equipment, such as the high-class trains of to-day, thereby reducing switching, will undoubtedly add much to the computed capacity of the terminals in times of pressure, as it is apparent that a continuous movement of trains in one direction is much more conducive to smooth and rapid handling than the usual back-up movements required in stub-end terminals. It would be interesting to the

Mr. Harwood.

Profession to know the cost of standing space per car, exclusive of the cost of the station building.

If the Pennsylvania could have waited a short time, it would have avoided the large and expensive car battery charging plant, which, with the latest accepted form of car lighting, seems to be unnecessary.

The organization for carrying on this work seems to have been most complete, and included many outside specialists not directly connected with the railroad. It would be interesting to all engineers to know the proportional cost of engineering and supervision on a work of this magnitude, where so much high-grade talent was required, as it is possible that the generally accepted figure, 5%, for engineering and supervision, would not hold true under these conditions.

In closing, the writer wishes to congratulate both the Pennsylvania Railroad and Mr. Gibbs on the results obtained, and only hopes that the new Grand Central Terminal, when completed, will be as free from proper criticism as Mr. Gibbs' work.

Mr. Storer.

N. W. Storer, Esq.*—The engineer who has read the paper by Mr. Gibbs, and who understands the work, must express his heartiest appreciation, both to the management of the Pennsylvania Railroad, and to Mr. Gibbs and his able corps of assistants, who have carried out this great work.

That part which is of greatest interest to the speaker is the motive power which propels the heavy trains. It is well understood, of course, and has been explained by Mr. Gibbs, that the entire project was predicated on the use of electricity in the tunnels. Without it the improvement would have been impossible, at least at this time.

It has been the speaker's privilege to follow this work from the very beginning, and especially the locomotive question. With the engineers of the Pennsylvania Railroad, he has passed through the various stages of experimental work, and association with these engineers and designers has given him an understanding of the success of this great railroad which would have been difficult to obtain in any other way. It is the absolute faithfulness and fidelity of the engineers to one idea, that of safety and reliability, which has made this railroad what it is. Absolutely nothing is allowed to interfere, questions of cost entering in only after the maximum of safety and reliability has been secured. This is why the reliability record for its electric locomotives has excelled that of almost every other locomotive, either steam or electric, ever built.

The locomotives were built only after the most careful and painstaking investigation of all existing types and the construction of several new types; and, since being placed in service, their maintenance has been of such a high order that a locomotive detention is practically

*Engineer, Railway Department, Westinghouse Electric and Manufacturing Company.

unknown. They have made a remarkable, a wonderful, record, hauling loads exceeding by 50 or 60% that for which they were guaranteed. Mr. Storer.

It may be of interest to outline somewhat briefly the reasons for adopting the design. It is well known that the grade leading into and out of the tunnels is about 2%, corresponding to that on the mountain division of a railroad, and naturally requires a heavy pulling engine. The ordinary consolidation engine, having four pairs of driving wheels, will exert a maximum tractive effort of about 40 000 lb. Some go a little higher, but that is the ordinary maximum tractive effort. It was required that this electric locomotive should be able to exert such a tractive effort, in order to start the normal weight of trains (500 tons trailing) on a 2% grade. Another requirement was that, on account of possible bad rails in the tunnel at some periods of the year, the engineers would not permit more than 20% of adhesion to produce this tractive effort. It was necessary, therefore, to have a weight of at least 200 000 lb. on the driving wheels. Then, as the tunnel would not permit that total weight to be concentrated on any very short wheel base, it was necessary to break up the driving wheel base. The investigation of the Railroad Committee, leading up to this design, went to prove that the wheel base, if unsymmetrical, would produce much less lateral stress on the track, as has been fully explained by Mr. Gibbs. Breaking up the main driving wheel base really necessitated making the machine an articulated locomotive, because of the length to which it had to be extended. This made a very economical design, because the two halves are interchangeable, thus reducing the number of spare units.

The requirement that there should be 200 000 lb. on the driving axle made it advisable, in order to avoid possible overloading of the motors, to make them of a capacity to handle any train which would be practicable with this weight on the drivers with good rails, and the electrical equipment was designed with that end in view. Consequently the locomotives are able to handle trains of 800 (instead of 500) tons because of the high coefficient of adhesion. In fact, the dynamometer test on the first of these locomotives showed a maximum draw-bar pull of 79 200 lb. on the dynamometer car back of the locomotive.

This corresponds to a coefficient of adhesion of about 37 or 38 per cent. This is very high, but it is not unusual, as such adhesion has been repeatedly developed, both with direct- and alternating-current locomotives. When one considers that 79 200 lb. about equals the draw-bar pull developed by one of the largest Mallet locomotives, one can understand the great capacity of this machine. It is, in fact, capable of developing a tractive effort equal to that of the heaviest freight locomotives, and, at the same time, to operate on the level track outside of the tunnel at regular passenger-locomotive speeds. It is

Mr. Storer. probably the most powerful locomotive ever built for all-around service.

The question of transmission between the motors and the driving wheels was considered by the Committee with the greatest care, and it was only after a very exhaustive study that the side-rods were adopted; and, while the Committee fully recognized the difficulty in the design and the disadvantages of the side-rods, it was felt that, on the whole, they were more reliable and safer than any other form.

The speaker believes that the test has shown the wisdom of the choice of side-rods, though he does not like their use on electric locomotives. The problem is very different from that of steam locomotives, because in the latter the power of only one cylinder is transmitted through any driving pin, and the two sets of rods are independent of each other, except as connected through the wheels. On the electric locomotive, however, the two sides are connected rigidly through the motor shaft, and, at certain points in the revolution, the entire power developed by the motor must be transmitted through a single pin. This makes it necessary to have all pins and rods heavier than those in a corresponding steam locomotive. The motor and jack-shaft bearings must also be designed to carry enormous reciprocating pressures.

This will be better understood when it is shown that the registered maximum dynamometer pull of 79 200 lb. corresponds to a pressure of 120 000 lb. on the crank pin.

The speaker has stated that he does not like the side-rods on electric locomotives, but, lest he be misunderstood, he wishes to say that if the same problem were presented to him at this time he would vote for side-rods, just as he did before. He knows of no other transmission system which could handle the service as well without a very radical change in all the plans. If the weight is to be confined to four pairs of drivers, if a single unit is desired, as at the present time, he believes that side-rods are practically the only form of transmission between the motors and wheels which would give the satisfactory operation secured on this locomotive.

Mr. Gandolfo. J. H. Gandolfo, Assoc. M. Am. Soc. C. E. (by letter).—To those who are familiar with New York City and its environment, one part of Mr. Gibbs' paper stands out prominently, and that is his description of the Station Building. It is the one feature in which the public, especially the traveling public, is most directly interested, and it is to this section of the paper that the writer proposes to confine his discussion.

In a building, of whatever nature, the object for which the structure is intended should be given first importance, and all details should conform to and be in harmony therewith. The primary object of a

great railroad station and terminal (aside from the handling of trains) is to convey passengers to and from trains as expeditiously and with as little inconvenience as possible. Mr. Gandolfo.

Has this been fully accomplished in the Pennsylvania Station, and has full advantage been taken of the fact that this is a station of the overhead type? On page 239, in speaking of terminals adjacent to the tracks, Mr. Gibbs says: "this plan has disadvantages * * * in the enormous distances between the head-house facilities and the point where the passengers board the trains," and, in mentioning the advantages of the overhead type, he says: "when passengers arrive at the station, they are at the nearest point to the one where they embark on the train." It seems to the writer that these requirements, to a greater or less extent, have been lost sight of in the final design of this station, and he proposes to call attention to such lack of co-ordination of detail as has come under his notice. In this discussion reference is made to only that part of the station above the track floor and used by the general public; and the question will be treated as a problem between the engineer and the public.

It may be stated as a primary fact that the greater part of the traveling public will arrive at the station on foot, and, as the heart of the city and the main arteries of the city's travel are east of the station, it is from this direction that most travelers will come. This fact has been recognized by placing the main façade of the station on Seventh Avenue.

On the first visit to the Pennsylvania Station one is impressed, and, it may be said, almost overwhelmed, by the size, space, and vastness of everything. However, when one enters the station as a traveler, perhaps carrying a heavy bag, one begins to wonder why it is necessary to walk a couple of blocks, after reaching the station, before "getting anywhere." On arrival at any point along the Seventh Avenue front it is necessary to pass through the main vestibule, traverse the arcade, cross the width of the dining-rooms, descend a long flight of steps, and cross the main waiting-room before reaching the ticket booths, a distance of more than 400 ft. within the station alone, not including any distance traveled in the street. If one goes down a side street and enters by a side door, the distances traveled are as great. There is a slight saving in distance if passengers arrive by the 34th Street cars and land at the 34th Street end of the private street through the middle of the block, but there is still the entire block between 34th and 33d Streets to be traversed before reaching the 33d Street entrance to the main waiting-room.

In order to attend to baggage, after purchasing tickets, the traveler must retrace his steps across the main waiting-room, and then, to reach the train gates, he must re-cross this room, cross the width of the sub-waiting-rooms, and, on arrival at the concourse, travel from 100 to

Mr. Gandolfo. 200 ft. more before reaching one of the train gates. Then there is still a long flight of steps (two stories) to descend in order to reach the platforms. Thus the traveler has walked some 800 or 900 ft. within the station in going from Seventh Avenue and attending to the simplest requirements of travel. If such things as telegraphing, telephoning, or similar business are necessary, this astonishing distance may be greatly increased. That the public is fully alive to this state of affairs may be summed up in the statement of the gentleman who said: "The Pennsylvania Railroad should organize a terminal railway to carry passengers about the station."

The foregoing brief description applies to the main train-shed. With reference to the Long Island Railroad section, although the total distances passed over are not so great, the arrangement is even worse. The traveler arriving at Seventh Avenue and 33d Street must pass down 33d Street about 250 ft. to the Long Island entrance. He makes a turn of 180° and travels, under ground, in the opposite direction, descending two stairways to the level of the Long Island concourse. Here the two streams of passengers going to and coming from the ticket booths tend to conflict, because, on account of the position of these booths, the passenger, after getting his ticket, must turn again 180° and practically retrace part of his course in order to reach the concourse and the train gates. Thus he has turned back along his path twice on this journey, and has traveled parts of the distance three times. It may also be said that the Long Island concourse seems to be entirely too small, even for handling the present traffic. On several occasions the writer has seen it uncomfortably crowded.

If thoroughly familiar with the station, the Long Island traveler may pass directly down the carriage ramp from Seventh Avenue and 33d Street, but the distances are just as great by this route, and the turns are the same, the only difference being that the first flight of steps is avoided; if he arrives by way of the private street, the distances traveled are even greater. Thus it is easily seen that, as far as distance to train gates is concerned, no advantage has been derived from the fact that this is a station of the overhead type.

In attempting to analyze the reasons for this unfortunate state of affairs, three causes seem to force themselves upon the investigator, as follows:

First.—The entire Seventh Avenue end of the station, 400 ft. long and extending back more than 300 ft., has been given up to shops, arcade, restaurant and dining-room, and runways, instead of being devoted to the primary purpose of the building. On page 239 Mr. Gibbs says: "its design has not been subordinated to the purposes of a hotel or office building." The design, however, has been to a great extent subordinated from the "primary object," in order to provide

space for the arcade and shops along Seventh Avenue—space which should have been devoted to other purposes. Mr. Gandolfo.

Second.—There are too many stairways throughout the building, instead of broad ramps, such as are used in the Hudson Terminal at Church Street.

Third.—The evident desire of the designers was to build a symmetrical and monumental structure. Without doubt, this should have been done, but the execution should have been made subordinate to practical station considerations. This has made the distances between different essential parts of the terminal too great to be easily traversed. The handling of crowds is not so much a question of great space, as of dividing up the crowd and keeping the units moving in one direction, with as little delay and retracing of steps as possible.

Having stated briefly some of the facts as they exist, and having drawn conclusions as to the reasons for this structure seeming to fall short of what the general traveling public would naturally expect, it remains to show what would have been a much preferable plan. In describing this general scheme, however, it should be understood that it is the merest outline, and that no attempt has been made to work it out in detail. It must be taken only as a preliminary study.

Instead of giving up the Seventh Avenue end of the building to shops, arcades, etc., it should have been designed to house the essential features of the station. This is the part of the structure which is nearest to the heart of the city and the traveling public. In addition to an entrance opposite 32d Street, main foot entrances should have been provided at the corners of 31st and 33d Streets. Indeed, it might have been preferable to make practically all the Seventh Avenue front into entrances. Bureaus of information, ticket booths, main and auxiliary waiting-rooms, baggage- and parcel-rooms, and concourse, should have been arranged in approximately the above mentioned order, so that the traveler would follow a natural sequence from entrance to train gate. Such auxiliaries as dining-rooms, shops, etc., should have been located at the sides or beyond the principal parts of the station, and just off the main lines of travel. The entrances to the carriage runways should have been preferably located on the side streets, so as to avoid the direct interference between vehicular and pedestrian travel such as now occurs at the corner of Seventh Avenue and 33d Street. This interference of the two classes of travel at this corner is one of the most serious problems to which this design has given rise, and it is one which will become worse as both kinds of traffic increase.

In order to avoid, as much as possible, so many stairways, ramps should have been used to descend from the street level to that of the main concourse. Such ramps should have been arranged to lead

Mr. Gandolfo. directly from the street entrances to the concourse level; or, after a detailed study of the problem, it might have been found advisable to place them between the waiting-rooms and other station auxiliaries, or between the waiting-rooms and the concourse.

In regard to the third reason given above, the writer does not feel called upon to discuss it in detail. All through the description of the station, and especially that part written by Mr. Richardson, the dominant idea, frankly stated, seems to have been that a monumental building was to be produced. There is no doubt that the station is a beautiful structure, both as to its general outward appearance and its interior finish. Standing on the steps and looking into the main waiting-room, everybody must admit that it is certainly imposing. The foregoing discussion of operating conditions, as exemplified in actual practice, is sufficient reason for thinking that too much attention was given to the monumental idea, making it dominate the more practical considerations.

The writer regrets that the time at his disposal does not permit him to analyze in detail (*a*) the exit concourse, where long distances must also be covered by the arriving passenger before reaching the main exits; (*b*) the position of the baggage- and parcel-rooms; (*c*) the lavatories; and (*d*) the elevators. He trusts that such points as he has been able to bring out will be of use in future designs of terminal stations. He hopes it will be fully understood, also, that there is nothing personal whatever in this discussion, as the problem has been treated purely from an engineering standpoint, and that he, having been connected with some of the largest transit and other developments in New York City, fully realizes the difficulties that confront those entrusted with the direction of such works.

Mr. Hill. E. R. HILL, M. AM. SOC. C. E. (by letter).—As the writer believes it would be of interest to present at this time certain information regarding the operation of the New York Tunnel Extension during the first ten months which have now elapsed since the opening of the line and station, he has secured from the Operating Department the following data as to performance, bearing chiefly on the growth of business at the station and the reliability of the train service under electric operation:

Station and Train Service Data.—

Station opened for Long Island Railroad service..	Sept. 8th, 1910
Station opened for Pennsylvania Railroad service.	Nov. 27th, 1910
Days of operation since November 27th, 1910...........	308
Number of train movements to and from station.......	148 830
Number of car movements to and from station..........	637 948
Number of locomotive movements to and from station...	87 614

Mr. Hill.

Average number of train movements per day............	430
Average number of car movements per day.............	2 070
Average number of locomotive movements per day......	290
Average number of Pennsylvania Railroad passengers per month for first three months...................	263 916
Number of Pennsylvania Railroad passengers for September, 1911..................................	346 254
Percentage of increase in period......................	31
Percentage of increase in Pennsylvania Railroad ticket sales at station in same period....................	41.5
Average number of Long Island Railroad passengers per month for first three months.....................	341 190
Number of Long Island Railroad passengers for September, 1911..................................	657 226
Percentage of increase in period......................	92.5*
Percentage of increase in Long Island Railroad ticket sales at station in above period..................	161
Percentage of increase in Pennsylvania Railroad and Long Island Railroad ticket sales in same period....	55

Power System.—

Average monthly power-house output from December, 1910, to September, 1911, inclusive....	7 396 301	kw-hr.
Maximum output for one month (July, 1911)....	8 549 017	" "
Maximum output for one day (July 4th, 1911)..	349 934	" "
Maximum load for one hour....................	24 820	kw.
Maximum load for 5-min. load.................	36 200	"
Installed capacity..........................	40 000	"

The power-house was built in 1903 for the use of the Long Island Railroad, and was more than doubled in capacity prior to the opening of the station and tunnels. It is interesting, therefore, to note that there have been no delays to trains due to power being off the main traction system, either on account of power-house, transmission lines, or sub-stations, and only three cases where there were delays due to power being off the third-rail, one being on account of a grounded third-rail insulator, and two on account of the tunnel alarm system, one of the latter being on account of a box having been pulled in error by an employé and not reported.

Locomotive Operation.—

Locomotive mileage since November 27th, 1910.....	759 940
Failures due to short circuits....................	2
Control failures..................................	2

* The large increase in business of the Long Island Railroad is partly due to the heavy holiday and seashore travel during the summer months.

Mr. Hill.

Total number of locomotive failures causing train detentions	4	
Number of trains delayed by same	10	
Number of miles per failure	189 985	
Number of miles per train detention	75 994	
Average time per train detention	11.5	min.
Average elapsed time between failures	77	days.
Average elapsed time between detentions	30.8	"

In addition to the exceptionally reliable performance shown by the foregoing figures, the large margin in capacity of the locomotives has been of great value; each locomotive is guaranteed to handle a 550-ton train on the tunnel grades, while, in actual daily service, single locomotives are used for handling 800-ton trains.

Multiple-Unit Car Operation.—

Multiple-unit car mileage since November 27th, 1910	609 318	
Number of failures causing delays, due to blowing of fuses	9	
Number of motor failures	2	
Number of control failures	3	
Number of other train failures	3	
Total number of failures causing train detentions	17	
Number of trains detained by same	23	
Number of miles per train detention	26 500	
Number of miles per failure	35 800	
Average time per train detention	7.95	min.
Average elapsed time between train detentions	13.4	days.
Average elapsed time between failures	18.1	"

These figures indicate the reliability of the electrical installation. It is not unusual with new machinery, especially in an extensive and complicated system, to have a considerable number of delays in the service due to defective workmanship and materials, and to some extent due also to defective design. The results obtained in this case would appear to justify the course adopted of not only purchasing materials and apparatus on very rigid specifications, but also the importance of instituting a very complete system of inspection, both at the makers' works and in the field during construction and installation, as well as thorough tests after the completion of the installation. By this system a number of defects are known to have been corrected, which would have resulted in serious delays had they not been discovered until after the road was put in operation.

Mr. Gibbs.

GEORGE GIBBS, M. AM. SOC. C. E. (by letter).—In closing the discussion, the writer desires to thank those who have so kindly furnished interesting information regarding certain details of terminal station

design, thus adding to the value of the series of Pennsylvania Terminal papers published by the Society, and special attention is called to the record, presented by Mr. Hill, of the first year's practical operation of this important terminal, which shows quite remarkable smoothness of performance and freedom from equipment troubles of any kind. It will be recognized by the Profession that such a record is a source of great satisfaction to the officials and engineers who have labored so many years to bring the project to a fitting conclusion. Mr. Gibbs.

The writer's paper was intended to present in a concise form the purpose and design of the terminal railway, and engineers will readily see that his chief difficulty was to deal in a general way with the immense amount of detailed design involved and, at the same time, say anything of engineering value. Each topic, therefore, could be mentioned in the briefest manner only; the reasons for the conclusions were stated briefly, but the discussion leading up to these conclusions, involving a comprehensive study of terminal conditions in America and abroad covering some four years, could not even be referred to, nor could mention be made of the progressive modification of the design of different features, as the interdependence of each on the whole problem was brought out in course of the designing. In the extensive committee work required of the Pennsylvania officials, it was apparent that many differences of opinion would be expressed as to detail, and that the conclusions developed were the result of the combined thought of many practical operating men in the various departments. The labor of investigating the suggestions, in order to ascertain their bearing before incorporating them in the general design, was very large, but it is believed that the results attained will amply justify the painstaking care of so many minds working on the problem.

Some of those who discuss the paper refer at some length to certain special operating features, and this enables the writer to expand his previous reference to them, for further elucidation of the conclusions reached.

Considering, first, the adopted location of the Station: this was decided on as the result of deliberate judgment, but was dictated principally by physical limitations. It should be remembered that the Pennsylvania Railroad built this Station after the growth of the city around it, not before. This is unlike the case of other large stations; for instance, the Grand Central Station of the New York Central and Hudson River Railroad was located at 42d Street years in advance of the dense city growth north to that point; the South Station at Boston was placed at the edge of the commercial district, far distant from the residence district, and with no possibility of becoming more central in the future; the Washington Station was driven out of the business district of that city by limitations of space,

Mr. Gibbs. the desire of the United States Government to develop a comprehensive plan for city beautification, and for other local reasons; the Broad Street Station in Philadelphia was also located in advance of the city's present dense growth around it, and to-day the Company is facing the very serious problem of its necessary enlargement under most burdensome restrictions, both physical and financial; in Chicago, the Northwestern Railway Station is relatively distant from the commercial center; and other examples might be cited of important stations, both in America and abroad, which were either established before the cities in which they are located grew up around them or which are now some distance from the densest development. The Pennsylvania Station, on the other hand, is located immediately on the western edge of maximum city development, and in the center of the business, hotel, and recreation district, which is bounded on the north by Central Park; and yet it is only one block from the main city artery, Broadway. In other words, the location is the very best for the great mass of the traveling public who need transportation facilities frequently. It is located near the geographical center of the district, which means that it has territory on all sides susceptible of growth; in the future, therefore, the station must become more central rather than less so. Its present inaccessibility is partly real and partly imaginary; it is real in so far as there exists no distributing rapid transit system at its immediate door; it is imaginary as far as other means of transportation are concerned, namely, by street car lines and cabs. People who have not been accustomed to take Pennsylvania trains at 32d Street and Seventh Avenue may possibly find it at first rather strange to go there for them, but this feeling will disappear upon acquaintance.

The lack of progress of rapid transit by city subways is, in fact, deplorable, both from the standpoint of the public and that of the public spirited corporation which has built, without aid or favor from the City, a magnificent and adequate public convenience, in the faith that the logical development of the existing rapid transit system (which means a subway line at the station door) would be forthcoming at the proper time. No one could reasonably foresee that the lack of outspoken public interest and the failure of the public officials to concentrate on a plan for the completion of the present city subway on the "West Side" would have resulted in leaving unfulfilled the clearly-defined plans and promises of the former Rapid Transit Commission, the Chamber of Commerce, and other important public bodies.

Some of those who have discussed the paper have wondered why the Station was not located at Sixth Avenue and Broadway, instead of at Seventh Avenue; this query may be answered by saying that it was thought to be unwarranted and short-sighted to add to the existing confusion of traffic in Greeley Square (Sixth Avenue and Broadway) by attempting to make the main entrance to such a great station

directly at one of the points of worst congestion in the city. The wisdom of the Company's decision should be apparent from an inspection of the conditions at the point in question, where are found grade crossings of three important street car lines, and elevated railway columns in Sixth Avenue in the middle of intercepting streets. The City has even been obliged to purchase property at this point for street widening, but, in spite of this, the congestion will certainly become worse. The Company, therefore, exercised wisdom in looking ahead in its improvement, and in planning it, not only for the present, but for the future. Mr. Gibbs.

Some have criticized the giving over of the Station Building wholly to transportation purposes; the management will doubtless plead guilty to a desire to make the structure something more than a compromise; an honest attempt has been made, rather, in the planning of this magnificent structure, to devote it to its primary purpose, and to combine beauty with maximum public and operating convenience. In this day of intense commercialism, when it is considered admissible to build sky-scrapers on inside lots, and thus utilize the "sky rights" of one's neighbors, it may be considered unusual to design a building so that these "rights" are preserved for the benefit of the surrounding community. It should be again stated that the building is designed as a railway station, and conforms to the Company's views of expediency, from operating, engineering, and esthetic standpoints. In arriving at this conclusion, many preliminary designs were made, including those for a "sky-scraper" structure and also for a hotel, but these were abandoned when the objections to such structures were weighed against the advantages. A trunk-line station is not comparable with a terminal building, which may combine usefully a union of city rapid transit facilities with the functions of an office building; it may, indeed, be reasonably doubted if it is desirable to house within a building intended primarily for through transportation, hundreds of miscellaneous tenants, who can only be accommodated by some considerable sacrifice of the space desirable for railway operating features, and whose presence adds to the congestion necessarily attending the distribution of passengers at such a large central point.

Furthermore, as pointed out in the paper, the terminal yard was planned for maximum operating facilities in a minimum space. It was necessary, therefore, to have the greatest number of tracks and the greatest interconnection for switching, and this, in turn, meant the least number of building columns at the track level. Any plans which could be developed for a combined office and station building meant an increase of the track interspacing and a reduction of operating flexibility, as well as an unnecessary darkening of the area at the tracks. It will be noted that the space under the Pennsylvania Station is wholly or partly reached by daylight, a fact which adds not a little

Mr. Gibbs. to the cheerfulness of the surroundings and the facility in handling equipment. In a certain portion of the yard, plans were, in fact, made for the erection of a very large building covering that entire section; it was found, however, that, in addition to the necessary sacrifice of four yard tracks, the erection of a foundation platform for the building would cost in excess of the value of the same area of adjoining property; furthermore, on adjoining property a building would be unrestricted as to its character, which would not be the case were it placed over the terminal yard. Obviously, therefore, building over this portion of the yard is a question which should be left to the future, when property becomes more valuable. At such time, if desired, buildings can be erected over practically the entire yard west of the Post Office, including the area between Ninth and Tenth Avenues.

Some consider the distance to be traversed on foot within the Station excessive, and they attribute this to faulty design, or, perhaps, to a subordination of convenience to architectural effect. The walking distances, of course, are considerable; the designers were not dealing with a subway station, or with one of moderate capacity, such as would be suitable for a way-station in a small city. This station is intended to serve for a long time the needs of a great trunk-line railway, with its many connections (aggregating some 40 000 miles of railroad), terminating in the greatest city of the country; the building is one of the largest, if not the very largest of the kind, in the world, and is primarily for through passengers, but serves in addition a very large suburban community. It is to be used for trains from the Eastern States, by means of the New York Connecting Railroad, as well as those from the West and South. The necessary distances, it is believed, are reduced as far as consistent with the business to be handled, and are less than those in other large stations of the world. As there appears to be much misconception regarding this point, the writer has compiled the following table of approximate distances to be walked by a passenger taking a train at any one of several modern stations regarding which he has figures at hand:

Table of Approximate Distances to be Walked by a Passenger Taking a Train in Several of the Large Stations of the Country.

Pennsylvania Station—P. R. R. trains	680 ft.
Pennsylvania Station—L. I. R. R. trains	520 ft.
Broad Street Station (Philadelphia)	840 ft.
Jersey City (Ferry Terminal)	840 ft.
Washington, D. C	1 040 ft.
New York Central (Grand Central)	935 ft.
Chicago and Northwestern (Chicago)	800 ft.
South Station (Boston)	850 ft.

The figures given are for average conditions, that is to say, to reach the middle of a train of average length, placed on a track, presenting the average length of walk in the station for the passenger. Mr. Gibbs.

Furthermore, the figures are the general averages for all conditions at each station; that is, for passengers entering at the different regular points and taking a train; and, in computing the average for each station, the distance traversed by commuters who would not buy tickets is averaged with the distance through passengers are required to walk in securing tickets and checking baggage on the way to the trains.

From this table it appears that, in any large station, a passenger must walk from 500 to 1 000 ft. or more, depending on the facilities he desires to reach, and that the distances are quite uniformly large in all stations.

It will be noted that the distances in the Pennsylvania Station are less than in any other station for similar purposes. An examination of the plans and a careful reading of the writer's paper will show the reason for this fact; the Station is a bridge over the tracks, and the passenger is brought within the building, from any of the four adjoining streets to the center of the train platforms, and buys his ticket on his way to this central point of the tracks beneath. In other stations, having end or side houses, the distance to the central point for taking trains must be walked after making use of the station facilities. While it is manifestly improper to compare conditions in a trunk-line station of great capacity, having all the required railway facilities, with a city subway station, it may nevertheless be said that the distances to be walked in the Pennsylvania Station are little, if any, greater than those in many of the subway stations of New York City (including that of the Hudson and Manhattan Railway at Church Street), namely, from 400 to 500 ft.

The reasonable anticipation of the Pennsylvania Railroad Company, that a subway would be provided at its Station, of course, dictated to some extent the design and arrangement of facilities, and plans for these connections have been made so that the necessary connections can be readily constructed at the proper time, without changing the general features of the station design, and will result in a further reduction of the walking distances for local passengers.

Reference has been made to the addition, recently completed, of a separate waiting-room for the Long Island Railroad; this addition was not an afterthought, but was a part of the original plan, to be constructed when the Seventh Avenue subway was built; on account of the large increase in Long Island business, however, it was found advisable to provide the facilities in question at an earlier date than originally proposed.

Mr. Wilgus refers to the opportunity afforded by electric operation

Mr. Gibbs. of providing car storage yards adjacent to the terminal, to avoid dead-heading trains to outlying yards, and has adduced the conclusion that an expenditure of $12 000 000 for storage and cleaning facilities adjacent to the terminal would have been justified, provided dead-heading could have been largely obviated; he believes that a contiguous location would offer superior advantages, as regards convenience, flexibility, and uninterruptedness of car supply, and refers to the new Grand Central as a case in point. The writer does not understand, however, that in this latter station it is intended to do away with the storage and cleaning yard at Mott Haven, in fact, if he reads the plans correctly, no extended provision has been made for cleaning cars, or for Pullman and commissary facilities, as well as for changing wheels, etc., in the Grand Central Yard. Of course, in the case of the Grand Central, it was necessary to avoid as much dead-heading as possible because of the limited track facilities through the tunnel to the Harlem River, a condition which does not exist to the same extent in the case of the Pennsylvania Terminal Railway. The latter, at its Sunnyside Yard, in Long Island City, 3.5 miles from the station, has a space of 192 acres, sufficient to accommodate a large number of yard buildings and about 45 miles of yard tracks. The buildings are extensive, having a floor area of 135 000 sq. ft., and more than 25 miles of yard tracks are at present laid and fully occupied. It is difficult to see how all this necessary space could have been provided in the heart of Manhattan Island, and the writer believes that the movement to the outlying yard and around the loop, which returns the trains in the proper order without shifting, has added to, rather than detracted from, operating convenience and to the uninterruptedness of car supply to the Station. It will be noted that the Station Yard, nevertheless, has very considerable storage facilities (as shown by the tables in the writer's paper) for certain classes of trains, to be used during commission hours for locals, and for Philadelphia express trains, but such facilities cannot take the place of those made possible by an open-air cleaning, make-up, and storage yard, located where the room for and plan of tracks and buildings is less restricted.

In the course of Mr. Harwood's interesting remarks he refers to the use of separate small buildings located at various points in the yard, rather than a large central building, for housing employees. This subject was studied carefully in the design, and the separate buildings were found to be necessary, to avoid loss of time of employees in reaching their work, and danger in unnecessary crossing of main-line tracks; the towermen, in fact, are centrally located for the work controlled, and the train despatchers and yardmasters are placed where they can communicate most readily with the employees. Extended comment cannot be made on this point, however, without a detailed reference to the plans. Mr. Harwood also refers to the installation of

an expensive car battery charging plant at Sunnyside Yard, which he thinks may be unnecessary with the latest form of car electric lighting (presumably the axle generator lighting). In view of the fact that the Company was at the last moment obliged to increase its stationary charging facilities, to care for this latest lighting system, the writer fears that Mr. Harwood is too optimistic as to the possible simplification of this expensive facility. Mr. Gibbs.

Mr. Davies gives interesting information as to the Hudson and Manhattan Railway signaling system, which was likewise a problem of great importance and complexity, although quite different from that faced by the Pennsylvania. The latter Company had to solve two very intricate problems which did not occur on the Hudson and Manhattan. The most involved, perhaps, was that of block and interlocking through the main terminal yard. In this yard, interconnection has to be provided between four large switch-operating plants, in addition to the provisions of advance and route locking of signals through the yard. All these facilities had to be accomplished by selective track circuits and relays, complicated by the presence of the return traction current in the rails. In the tunnels, an overlapping block signal system with track stops was provided, arranged for lock and block, not only for normal but for reverse running on all tracks. It will be readily appreciated by signal experts that this problem was one of great complexity. The lock and block had to be automatic for following movements in both directions, with proper control of automatic stops in both directions under the condition of heavy grades, which meant that the location of signals and stops for one direction would not be suitable for those in the reverse, inasmuch as these are located with reference to maximum speed conditions on the grades.

Mr. Davies gives also some interesting information regarding the fluctuating air pressure noticed in the trains entering the tunnel sections; this effect was observed by the writer during the experimental running through the Pennsylvania Railroad tunnels before operation was begun, and a complete series of barometric tests was made, in order to determine the quantitative fluctuation and the reasons therefor. At a later date, the writer hopes to present to the Engineering Profession a record of these results.

Unfortunately, space will not permit of a further discussion here of the other points commented on, which are largely those of details in the design. The discussion on electric locomotives is especially interesting, and brings out clearly some of the advantages of the novel design adopted by the Company. It is satisfactory to be able to say that no important mechanical or electrical defects have developed in these locomotives during the first year's service.

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